Evaluation of Dammam Carrousel Treatment Plant for Nitrogen Removal

by

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A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CIVIL ENGINEERING

June, 1993

Order Number 1360405

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King Fahd University of Petroleum and Minerals (Saudi Arabia), 1993

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CIVIL ENGINEERING

JUNE 93

KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS

Dhahran 31261, Saudi Arabia

CIVIL ENGINEERING DEPARTMENT

This Master of Engineering Report written by ABDRABALAMIR AHMED AL-SENAN under the direction of his Advisor and approved by his Report Committee, has been presented to and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements for the degree of MASTER OF ENGINEERING IN CIVIL ENGINEERING.

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COLLEGE OF GRADUATE STUDIES

Dedicated to my parents and my wife Huda

ACKNOWLEDGMENTS

This field study was carried out at the Environmental Engineering Laboratory of the Civil Engineering Department, King Fahd University of petroluem and Minerals and at Dammam Mechanical Wastewater Traetment Plant.

Iam greatful to those people from Dammam Wastewater treatment plant who have helped me in the collection of wastewater samples. Also I must acknowledge with appriation the technical assistence of Mr. Essam El Deep and Mr. M.K. Abdulappa.

Finally, I wish to express my gradtitude and deep appritiation to My adviser, Shaukat Farooq and to my report committee member, Dr. G. Nakhla , whom with their great effort and time helped made this report possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A field study was conducted at the 55 MGD Dammam wastewater treatment plant employing the carrousel system, to evaluate its overall performance with particular emphasis on nitrogen removal. The results of the study showed that the plant achieved greater than 93% BOD removal, 99% ammonia reduction, and 93% TKN removal. The plant readily met the secondary effluent BOD_5 requirement with an average BOD_5 concentration of 8.2 mg/l, but rarely satisfied the SS standard with effluent SS averaging around 29 mg/l. While the average total effluent nitrogen was 4.4 mg/l, nitrification -denitrification accounted for about 45% of the total nitrogen removal. The system kinetics for BOD_5 and ammonia removal conformed to the plug-flow first-order kinetic model. Kinetic parameters estimated in this study were well within literature values.

خلاصة الرسالة

لقد تمت هده الدراسة الميدانية بمحطة المعالجة الميكانيكية بالدمام (نظام الكاروسيل). وقد استهدفت معرفة كفاءة المحطة التشغيلية وبتركيز أخص على كفاءة النظام في ازالة النيتروجين ومركباته. لقد بينت نتائج الدراسة ان محطة المعالجة تحقق تخفيض في الأوكسجين الحيوي الممتص بنسبة أكبر من ٩٣٪، وتقليص في النوشادر بنسبة ٩٩٪ ، وفي الأزوت الكلي بنسبة ٩٣٪. كما أظهرت النتائج ان المحطة حققت متطلبات المعلجة الثانية ودلك بمعدل تركيزي ٨،٢ مغم/ليتر، ٢٩ مغم/ليتر للمواد العالقة. وبينما كان معدل النتروجين الكلي بعد المعالجة ٤،٤ مغم/ليتر ، فان نسبة التأزت في نظام الكاروسيل بالدمام كان ٤٥٪ من المجموع الكلي للنيتروجين المزال.

هدا وقد وجد ان نظام الحركة لتقليص الأوكسجين الحيوي والنوشادر مطابق لنظام الحركة في التدفق المسدود (plug flow) من الدرجة الأولى. بالنسبة لمعاملات الحركة في هده الدراسة وجدت انها مقبولة ومطابقة للقيم المدونة في الكتب العلمية المتخصصة.

Chapter 1

INTRODUCTION

For many years, wastewater treatment plant effluent quality was measured in terms of two parameters : suspended solids (SS) and biochemical oxygen demand (BOD). Now however, this philosophy has changed and stricter effluent standards are imposed by regularity agencies to improve plant performance in terms of total pollution loads being discharged into natural water. This include removals of unoxidized nitrogen or total nitrogen and phosphorus, as well as biochemical oxygen demand and Suspended Solids.

The removal of nitrogen and nitrogen compounds are receiving great attention in any wastewater management program. This is mainly because of the ill effects that nitrogenous material can have on the receiving stream waters. Researchers have concluded in their studies that nitrogen in its various forms can deplete dissolved oxygen levels in receiving waters, stimulate aquatic growth, exhibit toxicity toward aquatic life, affect chlorine disinfection efficiency, and affect the sauitability of wastewater for reuse.

Nitrogen in wastewater comes in four different forms : organic nitrogen, ammonia nitrogen, nitrate, and nitrite. All forms are probably found in municipal waste, however organic and ammonia nitrogen are the principal forms in untreated wastewater.

In nature, a series of reactions converts organic nitrogen and ammonia nitrogen to nitrate (nitrification). The overall stochiometric reaction is :

$$NH_4^+ + 2O_2 \Longrightarrow NO_3^- + H_2O + 2\,H^+ \qquad (1\text{-}1)$$

It is very well known that in order for this reaction to go to completion, 4.3 mg of O_2 are required per 1.0 mg of ammonia nitrogen. Hence, this oxygen demand, known as nitrogenous oxygen demand (NOD) can produce significant depletion of dissolved oxygen in the receiving stream. To mitigate this problem, ammonia and organic nitrogen must be converted to nitrate or eliminated from wastewater.

Currently, nitrogen in its various forms can be removed from municipal wastewater by a number of biological and physicochemical processes (1). To date the most economical of these techniques is the biological one (2). Of the various biological processes, the activated sludge processes (Carrousel and Oxidation Ditch Systems) are the most commonly used processes for nitrification-denitrification (3).

The objectives of this paper are to describe the design, operation, and performance of the Dammam Carrousal wastewater treatment system, to evaluate the hypothesis that nitrification with denitrification occur simultaneously inside Dammam carrousel aeration tank, and finally to model the carrousel system mathematically.

Chapter 2

LITERATURE REVIEW

The literature review will briefly discuss the sources of nitrogen in wastewater and the most widely used process for their removal (Biological nitrification and denitrification processes).

2.1 Sources Of Nitrogen

Nitrogen and nitrogen compounds enter wastewater from both natural and manmade sources. Natural sources which contribute significant quantities of nitrogen include runoff and rainfall . Further , little contribution come from precipitation and dustfall . On the other hand, manmade sources include both domestic and industrial wastes , farm waste from animals , and runoff from agricultural land.

Numerous researchers have studied the contribution of nitrogen from various sources. Eliassen and Techobanglous (4) estimated domestic waste contribution to be in the range of 18 to 20 mg / l (as N). Rohlich (4) found that typical raw wastewater has ammonia in the range of 21.9 to 32.4 mg/l, organic nitrogen in The range of 18.2 to 26.3 mg / l, and nigligable nitrate level. Other researchers (2) estimate nitrogen concentration in raw municipal wastewater to be in the range from 15 to 50 mg / l , in which ammonia nitrogen represent 60%, organic nitrogen 40%, and negligible amount is nitrate and nitrite nitrogen .

Runoff from livestock feed lot constitute a high strength organic waste source. Studies have shown that ammonium is a major constituent of feed lot waste , in which ammonia nitrogen concentration may reach 300 mg / l and organic nitrogen concentration make up to 600 mg /l (4,5). Urban runoff is also a big source of nitrogen. A study made in Cincinnati showed that total nitrogen from urban runoff fall is around 2.7 mg / l (6). In addition, similar studies conducted in Washington DC showed that the total nitrogen from urban runoff is about 2.1 mg / l (7).

2.2 Biological Nitrification - Denitrification Processes

Among the many processes, the most used method geared specifically for nitrogen removal is nitrification - denitrification .

2.2.1 Nitrification Process

Is a microbiological process during which ammonia and some organic nitrogen are oxidized to nitrite and then to nitrate. It is a two step process that is mostly carried out by two groups of autotrophic bacteria. Those two groups of organisms use CO_2 as a source of carbon for cell material and obtain energy for the process from the oxidation of reduced forms of inorganic nitrogen. In the first step of the process, ammonia is oxidized to nitrite as shown by the following reaction (8) :

$$NH_4^+ + 1.5\ O_2 \Longrightarrow 2\ H^+ + H_2O + NO_2^- \quad 58\text{-}\ 84\ \text{Kcal / mol} \qquad (2\text{-}1)$$

Nitrosomans is the most commonly identified organism for this step. But other genera , such as Nitrosolobus, Nitrosococcus, Nitrosovebrio, and Nitrosospira can oxidized ammonia to nitrite.

In the second step of the process, nitrite is oxidized to nitrate by an autotrophic bacteria called Nitrobacter. The energy yielding reaction is as follow (8) :

$$NO_2^- + 0.5\ O_2 \Longrightarrow NO_3^- \quad 15.4 - 20..9\ \text{K cal / mol} \qquad (2\text{-}2)$$

The overall oxidation reaction would look as follow : -

$$NH_4^+ + 2\ O_2 \Longrightarrow 2\ H^+ + H_2\ O + NO_3 \qquad (2\text{-}3)$$

Oxidation dose not take place alone. Synthesis also occurs resulting in the growth of additional organisms. Synthesis may be expressed by (8) :

$$15CO_2 + 13NH_4^+ \Rightarrow 10NO_2^- + 3C_5\ H_7\ NO_2^-\ \text{(Nitrosomonas)} + 23H^+ + 4H_2O \qquad (2\text{-}4)$$

And ,

$$5CO_2 + NH_4^+ + 10\ NO_2 + 2\ H_2O \Longrightarrow 10\ NO_3^- + C_5\ H_7\ NO_2\ \text{(Nitrobacter)} + H^+ \qquad (2\text{-}5)$$

A knowledge of cell yield will of course permit the combination of the oxidation and synthesis reactions. On that basis, the following overall equation for nitrifier synthesis and nitrification has been suggested by (8):

$$NH_4^+ + 1.83O_2 + 1.98HCO_3^- \Longrightarrow 0.021C_5H_7NO_2 + 1.04H_2O + 0.98NO_3^- + 1.88H_2CO_3 \qquad (2\text{-}6)$$

From this equation, the oxygen requirement for nitrification was found to be approximately 4.3 mg/l O_2 NH_4-N and alkalinity consumed during nitrification was 7.14 mg of alkalinity consumed as $CaCO_3$ per mg NH_4 - N oxidized. Those values matches very well with those found in the literature (8).

Nitrification may be performed in a CSTR with cell recycle, Packed Towers, and rotating disc reacters. In some cases nitrification occurs concurrently with the removal of organic matter in combined carbon-oxidation-nitrification reacters. While in another cases nitrification occurs in seperate stage. By that it is ment that oxidation of organic matter occurs in one reacter followed by nitrification in a subsequant one. The efficiency of those systems to nitrify is related directly to their ability to maintain adequate population of Nitrosomonas and Nitrobacter in the activated sludge floc. the principal factor which determine that is solids residence time (SRT). Therefore, in order for an activated sludge system to nitrify, it must maintain higher (SRT) than it is normally required for the removal of carbonaceous waste matter .

According to many studies, both combined and separate systems have shown their reliability to nitrify. In fact a study done on single stage systems (combined system) and two stage systems (separate systems) in order to find out how efficient those systems are in removing influent with ammonia concentration as high as 500 mg / l (9). The results of that study were very encouraging. Single stage proved its ability to remove more than 90 % of the ammonia, while the two stage system achieved more than 97 % removal .

2.2.1.1 Kinetics Of Nitrification

In considering the kinetics of nitrification, the expression postulated by Monod is the one that will be used to describe the knetics of biological growth of either Nitrosomonas or Nitrobacter.

$$U = U^{\wedge} (S) / (K_S + S) \quad (2\text{-}7)$$

Where ,

U = growth rate of microorganisms , day $^{-1}$

$U^{\wedge}$= maximum growth rate of nitrifier , day $^{-1}$

K = half velocity constant for nitrification, mg/l

S = concentration of growth limiting substrate in solution, mg/l

From the stochiometric equation mentioned earlier, the energy yield from the conversion of ammonia to nitrite is almost three times the energy yield from the conversion of nitrite to nitrate. And since K_S values for both organisms are less than 1.0 mg / l -N at a temperature below 20°C (10). Therefore, the rate limiting step in nitrification is the conversion of ammonia to nitrite by Nitrosomonas. Further, the rate of oxidation of ammonia can be related to the growth rate of Nitrosomonas by the following equation:

$$Q_n = U_n / Y_n = S / (K_S + S) \qquad (2\text{-}8)$$

Where ,

Q_n = ammonia oxidation - rate mg NH_4 - N oxidized / mg VSS T^{-1}

Y_n = growth yeild coeff. , mg Nitrosomonas growth / mg NH_4 -N oxidized

Other parameters of importance in characteristic microbial reactor is the decay rate, b. Table 2.1 shows the typical kinetics coeff. for nitrifier at 20°c (10).

2.2.1.2 Environmental Effects on Kinetics

Nitrification kinetics are strongly affected by a number of environmental conditions within the bioreacter including temperature, pH, and dissolved oxygen concentration (DO).

Temperature : the most widely accepted kinetic constant for the nitrifiers are those presented by Downing and co-workers (11,12). Their results are shown on Figures 2.1 and 2.2. Both of those figures show that maximum growth rate and half velocity constant k_S for Nitrosomonas and Nitrobacter are markedly affected

Table 2.1 : Typical kinetics coefficients for the activated sludge process.

Coeff.	Basis	Values: Range	Values: Typical
Nitrosomonas			
U_m	d^{-1}	0.3 -2.0	0.7
K_S	NH_4^+ - N mg / l	0.2- 2.0	0.6
Nitrobacter			
U_m	d^-	0.4- 3.0	1.0
K_S	NO_2^-	0.2- 5.0	1.4
Overall			
U_m	d^-	0.3- 3.0	1.0
K_S	NH_4^+ - N mg / l	0.2- 0.5	1.4
Y	NH_4^+ - N mg VSS / mg	0.1- 0.3	0.2
K_d	d^{-1}	0.03- 0.06	0.05

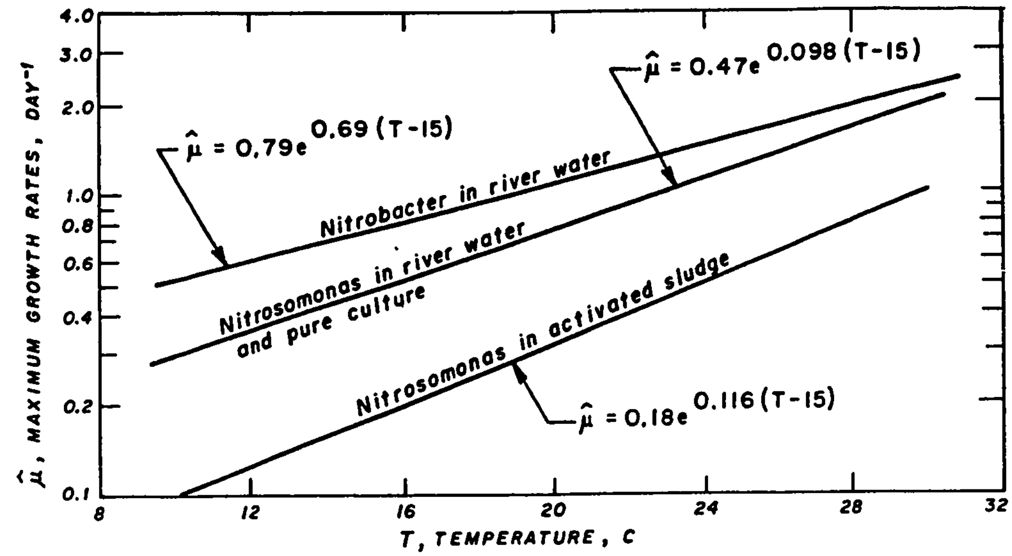


Figure 2.1 Temperature Dependence of the Maximum Growth Rates of Nitrification

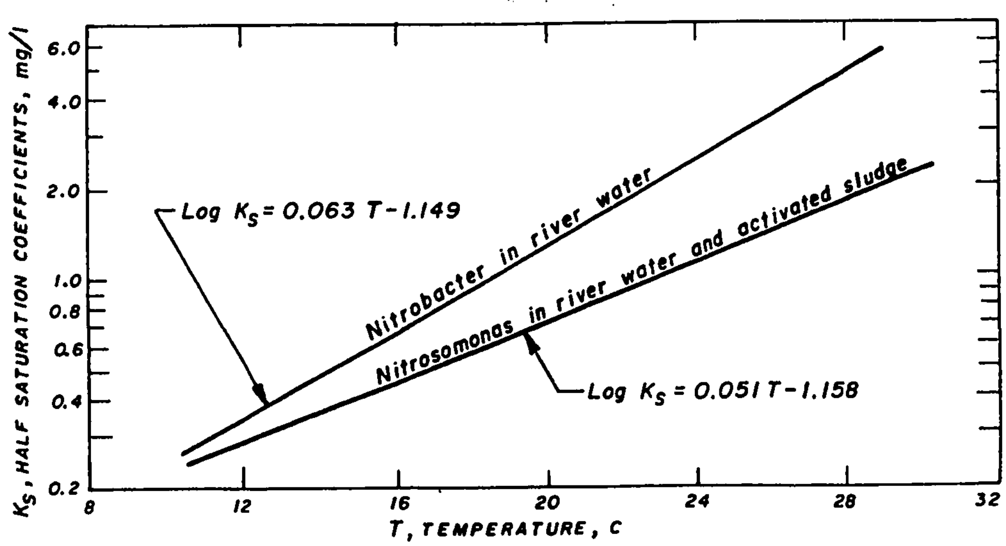


Figure 2.2 Temperature Dependence of the Half Saturation Constants of Nitrifiers

by temperature. Downing and co-workers have estimated the effect of temperature on k_s and $U^\wedge$ by the following expressions :-

$$K_S = 10^{0.05T-1.158} \tag{2-9}$$

$$U^\wedge = 0.47\, e^{0.098(T-15)} \tag{2-10}$$

In another study, the optimum temperature for nitrification has been reported to be in the 25^0 c to 28^0 range (13).

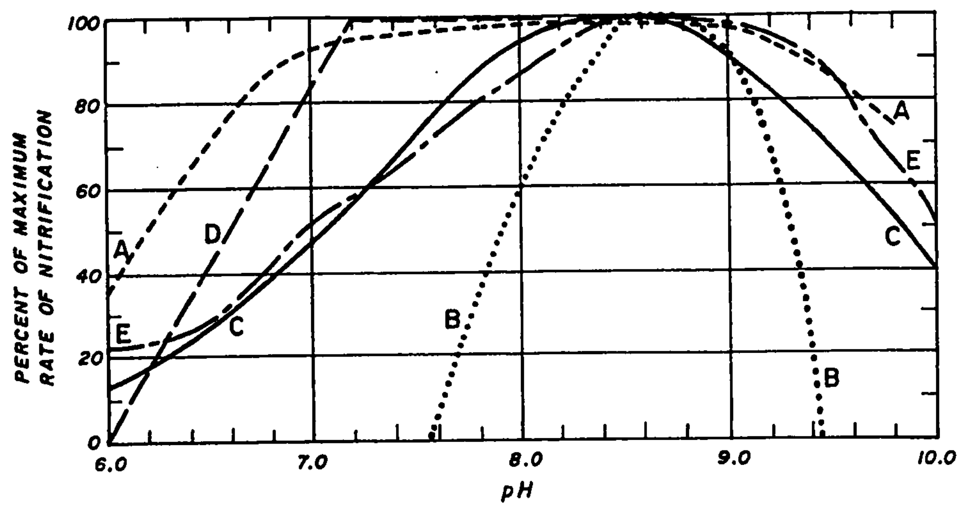
pH : Also it has been observed that for biological processes in general , the growth rate for Nitrosomonas and therefore the nitrification rate is affected by pH. Figure 2.3 present typical pH relationships for a number of invistigators (14,15,16,17,18). Those investigators generally agree that the optimum pH for nitrification lies between 7.2 and 8.8. As PH reduced below 7.2, the growth rate for Nitrosomonas is reduced. Downing and co-workers (17) have proposed that for pH values less than 7.2 .

$$U = U^\wedge [\, 1-0.833\,(7.2 - pH)] \tag{2-11}$$

This exression was developed for combined carbon oxidation - nitrification system.

DO : Finally, the concentration of dissolved oxygen (DO) has a significant effect on the rates of nitrifiers growth and nitrification in biological waste treatment.

Many researchers agree on the use of Monod type relationship to model



KEY

SYMBOL	ENVIRONMENT	REFERENCE
A	Nitrosomonas - pure culture	Engle and Alexander (14)
B	Nitrosomonas - pure culture	Myerhof (15)
C	Activated sludge at 20 C	Sawyer, et al. (16)
D	Activated sludge	Downing, et al. (17)
E	Attached growth reactor at 22 C	Huang and Hopson (18)

Figure 2.3 Effect of pH on Nitrification Rate
(After Sawyer, ET AL)

the effects of dissolved oxygen as follows :

$$U = U^{\wedge} (DO) / (Ko_2 + DO) \qquad (2\text{-}12)$$

where,

Ko_2 = half saturation cnostant for oxygen.

Studies conducted by the Los Angels County Sanitation Districts at its Pomona water renovation plant represnt one of the valuable attempts to evaluate the effect of DO on nitrification rate(19). The plant was single stage compined carbon oxidation - nitrification. During the study, sludge sample were withdrawn, dosed with ammonia and aerated at various DO levels. Nitrification rate determind from the data were plotted against DO levels as shown on Figure 2.4 . Monod expression as a function of DO was fitted. The Ko_2 determined from this data was 2.0 mg / l at unspecified tempreture but it was indicated that tempreture was about 20^0 c .

Several invistigator have shown the importance of DO and its effect on nitrification. For example, a pilot invistigation at metro sewer district in Cincinnati, Ohio showed that when DO held at 2.0 mg / l , only 40% nitrification occured , but when the DO was measured at 4.0 mg / l , about 80% nitrification took place (20).

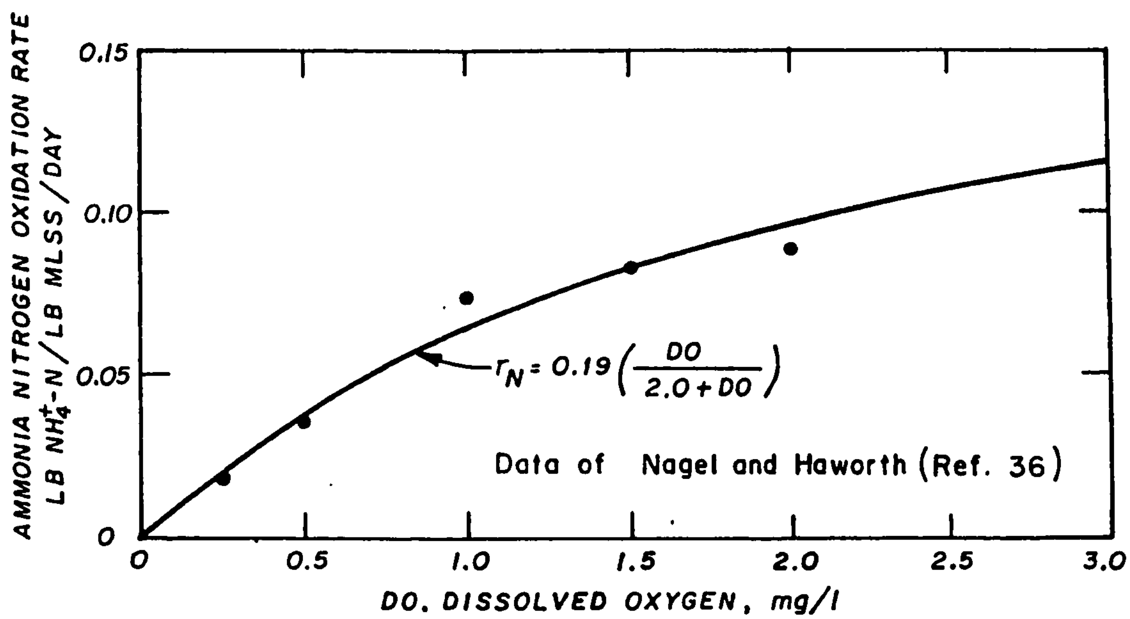


Figure 2.4 Effect of Dissolved Oxygen on Nitrification Rate

2.2.1.3 Combined Effect of Environmental Conditions on Nitrification

It is also possible to combine the effect of environmental conditions on nitrification kinetics using the Monod type equation as follow (21) :

$$U_n = [U^{\wedge} S / (K_S + S)] [(O_2) / (Ko_2 + O_2)] * (1\text{-}0.833 \, (7.2 - p)) \qquad (2\text{-}13)$$

Or ,

$$U_n = 0.47 \, e^{0.098 (T-15)} * [S / (10^{0.051 T - 1.158}] * [O_2] / (Ko_2 + O_2) * [1\text{-}0.833 \, (7.2 - pH)] \qquad (2\text{-}14)$$

2.2.2 Denitrification Process

Denitrification is a microbiological process. It involves the conversion of nitrate - N to nitrogen gas, which escapes from the liquid phase. Abroad range of organisms can accomplish this reduction including, Psuedomonas, Micrococcus, Bacillus, and Archromobacter. The process used for the reduction is called nitrate dissimilation, whereby nitrate on nitrite replaces oxygen in the respiratory processes of the organisms under anoxic conditions. Those organisms are called facultative heterotrophic bacteria because of their ability to use either nitrate or oxygen as the terminal electron acceptors while oxidizing organic matter.

Denitrification is also a two step process in which the first step is a conversion of NO_3^- to nitrite . The second step carries nitrite to nitrogen gas.

Methanol has been used widely as an electron donor. The stochiometric reactions of these two steps are as follow:-

$$NO_3^- + 0.33\ CH_3OH \text{-<====->}\ NO_2^- + .67\ H_2O \qquad (2\text{-}15)$$

$$NO_2^- + 0.5\ CH_3OH \text{-<=>}\ 0.5\ N_2 + 0.5\ CO_2 + 0.5\ H_2O + OH^- \qquad (2\text{-}16)$$

The overall transformation is :

$$NO_3^- + 0.833\ CH_3OH \text{<-=->}\ 0.5\ N_2 + 0.833\ CO_2 + 1.167\ H_2O + OH^- \qquad (2\text{-}17)$$

Biochemical denitrification process occurs naturally in many conventional water treament plant, and the resulting release of nitrogen bubbles is the primary cause of floating sludge in final settling tanks. In fact, early studies have proved that final settling tanks of an activated sludge system could be used for denitrification, but the operational problems in obtaining good results of solid removal from the final clarifiers and in maintaining a high quality effluent were insuperable. As a result, some researchers were advising to use seperate denitrification units to treat high quality effluent from a normally operated secondary treatment plant.

The three famous designs for denitrification to occur are : anaerobic activated sludge, anaerobic filter, and anaerobic lagoon. When treating a high quality purified effluent with either of these systems, methanol of organic carbon source must be added to the raw wastewater stream prior to denitrification. All of these designs have the proven to be successfull in the removal of nitrogen (22). However anaerobic lagoons faces certain problems including, long detention times which means the required volume is 30 to 60 times that required for anaerobic activated sludge of filter system, odor problems, and short circuting. Maccaty (23) acheived 90% removal of nitrates from water supply utilizing the anaerobic filter system and feeding methanol.

2.2.2.1 Kinetics of Denitrification

The kinetics of denitrification can be represented by Monod - based model :-

$$U_d = \hat{U_d} (D) / (K_d + D) \qquad (2\text{-}18)$$

Where ,

U_d = growth rate , day$^-$

$\hat{U_d}$ = max. dentrifier rate , day$^-$

D = concentration of nitrate nitrogen , mg / l

K_d = half velocity constant, mg / l NO_3^- - N

Also denitrification rate can be related to the organism grouth rate by the following relationship :

$$Q_d = U_d / Y_d \qquad (2\text{-}19)$$

Where,

Q_d = nitrate removal rate , lb NO_3^- - N remov. / lb VSS / day

Y_d = denitrifiers gross yeild , lb VSS grown / lb NO_3^-- N removal.

The value of K_d has been reported by numerous invisigators to be from 0.06 - 0.16 mg/l of NO_3^- - N (24,25). Therefore, at a concentration of 1.0 to 2.0 mg / l NO_3^-, the nitrate concentration has almost no effect on the rate of denitrification and approaches zero order rate.

2.2.2.2 Environmental Effect on Denitrification Kinetics

Temp. : Biological denitrification is more sensitve to temperature than aerobic heterotrophic process in waste treatment. The usual equation used to express the temperature effect is in the form of :

$$U_m (T^0 c) = U_m (20\,^0 c) * (O^{T-20}) \tag{2-20}$$

Where, U_m (T ^{0}c) & U_m (20^0) are the max.specific growth rate a t T^{0}c & 20^{0}c. Also O is temperature coeff. . Denitrification occurs between 0^0 c and about 50^{0}c with an optimal temperature of about 40^{0}c.

pH : The rate of denitrification is also affected by pH. Several studies have shown that the rate of denitrification is optimized in the pH range of 7.0 - 7.5, and it is reduced outside of the pH range of 6.0 - 8.0 (8).

Because of the high cost of denitrification processes and the organic carbon sources associated with it, new techniques have been developed in which the carbon oxidation nitrification - denitrification processes are combined into a single process without any intermediate steps. Of those, is the carrousel type oxidation channel system. The idea of the carrousel is based on biological oxidation of the waste with simulataneous aerobic sludge stabilization in one aeration reactor. This system hold promise as an effective means for nitrogen removal (80 to 90 percent or more can be acheived). Further, some of its advantages include : potential elimination of the supplemental organic carbon source (e.g, methanol) required for complete denitrification; creats a very high mixed liqoure recycle rate that provides NO_3^- for anoxic oxidation of incoming BOD_5 ; it allows carefull matching of oxygen transfer capacity to the required rate; and it provides for oxygen depletion and establishment of alternating aerobic and anoxic zones.

2.2.3 Case Studies

In the light of the universal nitrogen control rule, many carrousl and oxidation ditch systems have been built in the Netherlands (26) primarily because both systems can acheive greater than 98% BOD removal efficiency and greater than 90% total kjeldahl nitrogen removal efficiency thus facilitating compliance with the Dutch law of anti pollution requirement that calls for the reduction of the discharged of wastes that will withdraw oxygen from the receiving bodies.

In 1974 , the authority of Winter Swijic Wastewater Treatment Plant oxidation ran a study on Carrousel type oxidation system during the first 8 months (26). The study was aimed at finding the treatment effeiciencies of the plant for BOD, COD, TKN, and total nitrogen. At the time of the study, the plant was close to its daily design load of 4115 kg BOD_5 . The results of the study showed that average concentrations of NO_3^--N and TKN in the plant' s effluent were 9.4 and 3.9 mg / l, respectively, Thus indicating TKN removal of 93 % and a total nitrogen removal of 77.0 %. In fact by the end of April, denitrification improved and as a result total nitrogen removal rose up to 90 %.

Oxidation ditches are also good , nitrification - denitrification process. High percentage removals of nitrogen can be achieved 84 % COD removal and 97.6 % nitrogen removal eventhough the flow rate and BOD_5 loads were respectively 75% and 51% greater than design values (27). The results indicate that 2.4% of the influent nitrogen remained in the effluent and that 15.5% of the influent nitrogen was present in the waste sludge. Therefore denitrification to nitrogen was responsible for about 82% of the nitrogen removal. The same study reported a total nitrogen removal of 76% with as much as 62.7% attributed to nitirification-denitirification by the oxidation ditch system at Franfurt, KY waste water treatment facility. The multi-channel oxidation ditch system in Hauntsville, Texas had been reported to effect 99.6% ammonia nitrogen removal and 20% total nitrogen reduction by denitrification (28).

Chapter 3

OBJECTIVES OF THE STUDY

Recently a project for determining the process performance efficiency of some of the wastewater treatment plants in Saudi Arabia got funded by King Abdulaziz City For Science and Technology . One of these treatment plants chosen for the study was Dammam sewage plant. Part of this study will be the topic of this thesis and it concerns the evaluation of the hypothesis that nitrification with denitrification occurs continuously inside the aeration tank of the plant .

Dammam sewage treatment plant is operated under Water and Sewerage Directorate Eastern Province. It is located on Dammam - Jubail Highway four kilometers southwest of Dammam city. The plant is designed to handle a daily flow of 208810 (55.2 MGD). Sewage is mainly domestic and it is pumped to the plant from different pumping stations within the collection system.

The basic process used for the treatment of sewage is the activated sludge carrousel type. Incoming sewage is screened prior to pumping and grit removal, settled in primary settling tanks, and then directed to one of the eight aeration tanks. After biological treatment in the aerations, the flow is directed to the sea after chlorination, while the return sludge and the excess sludge are directed to the aeration tanks and sludge thickener respectively.

The field study on this treatment plant will specifically aim at finding the following :

1. Determining the variation of dissolved oxygen horizontally and vertically along the carrousel aeration channel. Four points were chosen for the test(see Figure 3.1).

2. Plant performance tests for ammonia Nitrogen, total kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, BOD, COD, PH ,DO, and other parameters as shown on Table 3.1. The samples will be taking from Influent, effluent, and from 4 locations along the carrousel channel as mentioned before.

3. Determining treatment efficiency for the whole testing period :

   a. BOD removal.

   b. COD removal.

   c. TKN removal.

   d. Ammonia removal.

   e. Total Nitrogen removal.

4. To model Dammam carrousel system mathematically.

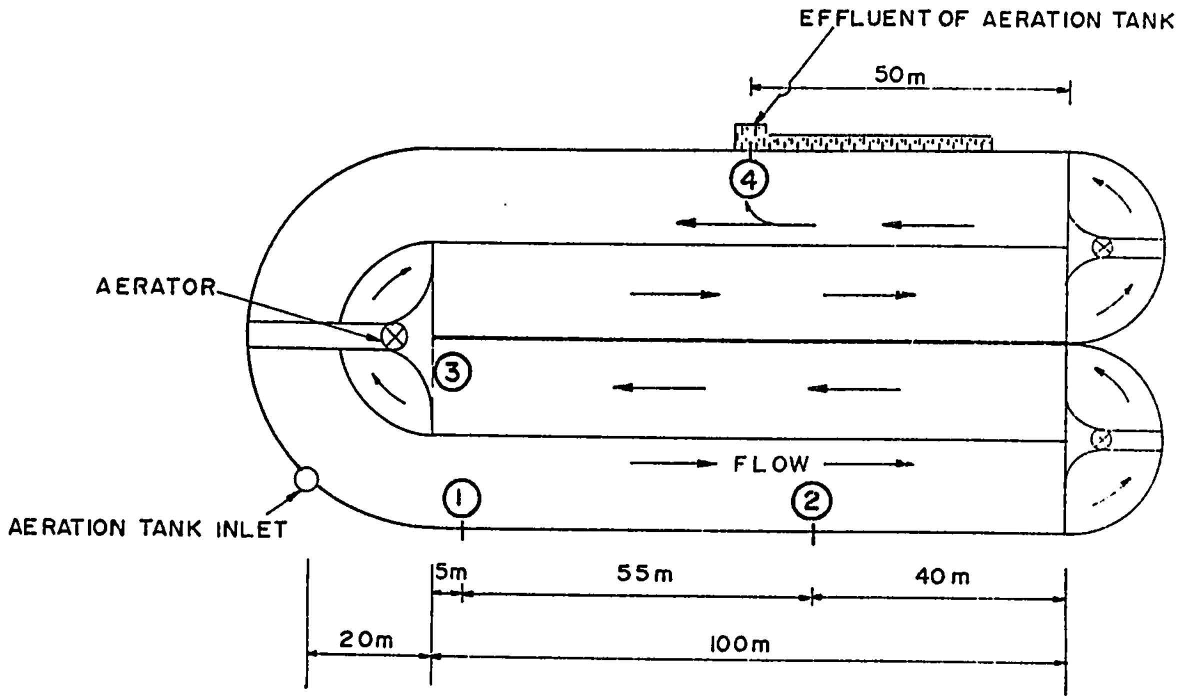


Fig. 3 . 1 Oxidation Ditch and Sampling Locations

Table 3.1 Sampling Schedule and the Parameters Tested at Different Locations

Dates of test/ type of test	Air tem p.	Water temp.	pH	DO	MLSS	VSS	Chlorides	BOD	COD	Grease &oil	Tot. phosph .	TKN	NH3	Nitrate	Nitrite
MAY 13/92															
MAY 20/92															
JUNE 24/92															
JULY 01 /92															
JULY 12/92															
JLUY 13/92															
JULY 14/92															
JULY 15/92															
JULY 16/92															
SEP. 21/92(6:00a.m.)															
SEP. 21/92(10:30a.m.)															
SEP. 21/92(03:00p.m.)															
SEP. 21/92(07:30p.m.)															
SEP. 21/92(12:00p.m.)															

Chapter 4

THE DAMMAM CARROUSEL SYSTEM

4.1 Facility Description

To cope with the increasing sewage flows due to increase in population Dammam Water And Sewage Authority have built a new sewage treatment plant with a design capacity of 208000 m3 /day to serve a population of half a million. The sewage treatment plant, which has been on stream since 1984 is located approximately four kilometer southwest of Dammam, on the western side of Dammam-Jubail highway. The basic process used for the treatment of sewage is the Activated Sludge carrousel system operated in the extended aeration mode.

The plant consists of primary treatment; carrousel type aeration tanks ; and secondary clarifiers. Sewage entering the plant is directed to the inletwork, where it is screened using mechanically racked screens, measured while passing parshall flumes, and degrited while passing grit removal tanks. From the inlet structure, sewage is delivered to the aeration tanks where it joins a constantly aerated and agitated mass called "mixed liquor", comprising of activated sludge and freshwastewater. There, sewage is purified by the action of bacteria present in the activated sludge.

From the aeration tanks, the mixed liquor flows by gravity to the sedimentation tanks, where separation of the treated effluent and activated sludge takes place. Treated effluent overflows a weir and is discharged to the outfall, while the activated sludge is returned to the aeration channel. The design return sludge recycle rate is 150% based on average flow and 75% based on peak flow (30). This is controlled by telescopic valves in the secondary clarifiers. Excess sludge is routed for disposal (See Figure 4.1).

The general layout and details of the plants are shown in Figure (4.2). All units are constructed of reinforced concrete.

4.1.1 Inlet works

It consists of a distribution chamber, 25 mm diameter screens, parshall flumes, and grits removal. The design velocity through the screens at peak flow is 0.86 m/s. Sewage entering the distribution chamber passes through screens and directed to the grit removal equipments. Those equipments are shown on Table 4.1.

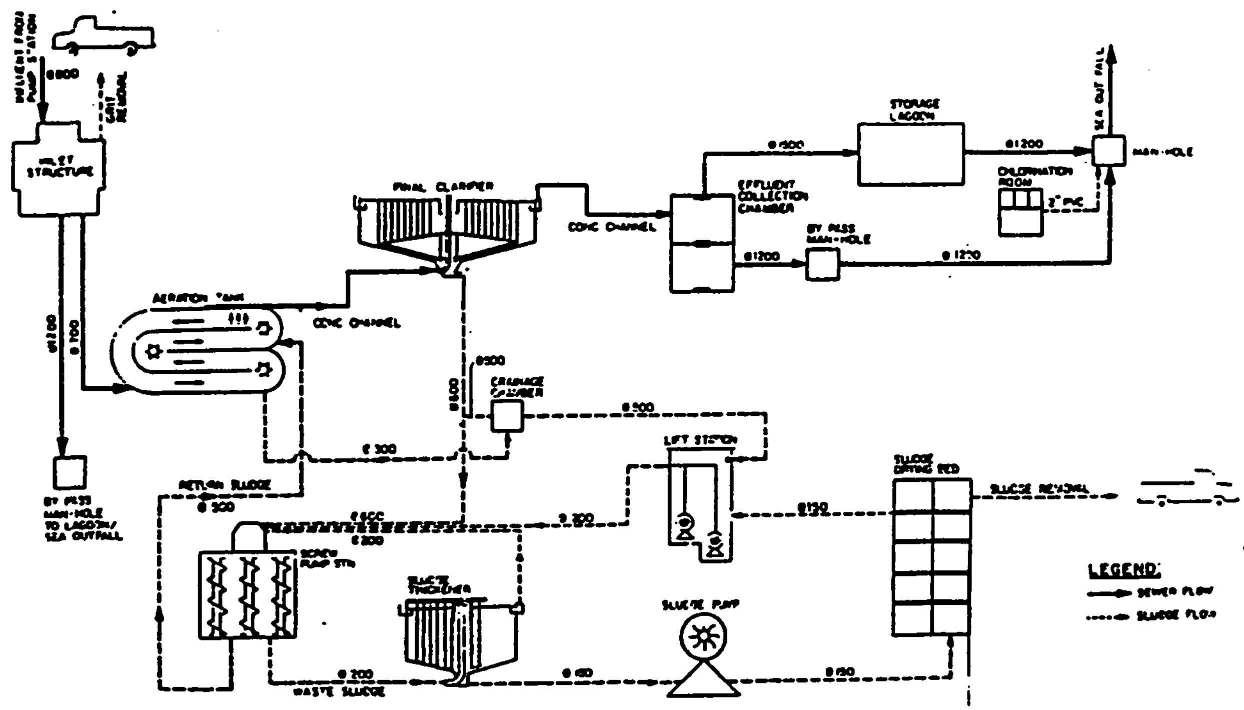


Figure 4.1 Dammam Treatment Plant Flow Process

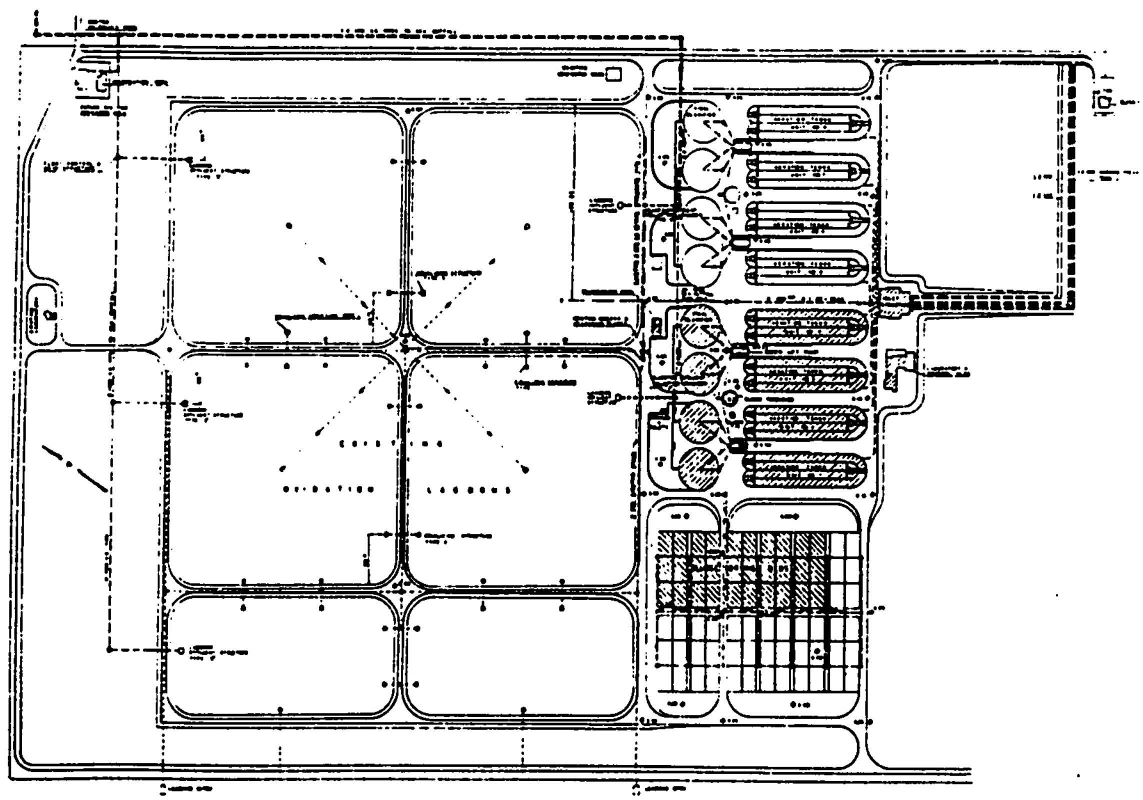


Figure 4.2 General Layout and Details of Dammam Treatment Plant

Table 4.1 Dammam Carrousel Plant Grit Removal Equipment.

Grit pumps		Grinders	
Number	2	Number	2
Type	wallwin	Type	Sulzer Horizental
Capacity (l/s)	13	Size	D-12
Head (m)	7	Motor Kw	18.5
Motor Kw	4		

4.1.2 Aeration Tanks

The aeration system consists of eight tanks with dimensions of 490.5m *8m*4m (length* width* depth) and total volume of 125600m3. Each tank contains 3-98hp vertical shaft aerators supported on concrete platforms spanning the tanks. Those aerators provide good mixing for the waste.

4.1.3 Final Clarifier

The plant utilizes eight circular Clarifiers with a diameter of 42m , a side wall liquor depth of 2.4m, a 1/6 bottom slope, and a central conical hopper. Each clarifier contains a circular glass fibre double sided launder unit with v-notch weirs.

4.1.4 Screw Pumps

The screw pumps in the plant consist of 12 screw channels with high and low level sumps, a motor room, and a control room. Each pump is designed to deliver 366 L/s against a lift of 4.6m. During normal operation, two screw lifts in each pump station operate continuously to return activated sludge into the carrosal channel via 500mm pipe, while the third unit remains as stand by.

4.1.5 Sludge Thickners

The plant employs 15m-diameter gravity thickeners with a side wall liquor depth Of 3.35m. Each thickening tank comprise of an area of 177m2 and a volume of 593m3. During normal operation, two sludge thickener operate continuously to thicken waste activated sludge.

4.2 Operating Conditions

A comparison between the operation and the design conditions is shown in Table 4.2. The table shows that the actual daily flow is about 68% of the design flow. The influent BOD_5 which the plant receives is very low compared to the expected design value. Also, in spite of the longer than the design detention time, the plant still operated to control MLSS level on the basis of maintaining 15 to 20 days sludge residence time (SRT). In addition, poor sludge settling characteristics, reflected by high value of sludge volume index (SVI) were observed. From the data collected on the performance of the plant, it was found that the average sludge volume index is about 200 ml/g which is greater than 50 to100 ml /g recommended by Viak (30) for good settling. Table 4.3 shows the average characteristic of Dammam raw sewage and final effluent. The average BOD_5 entering the system is 133 mg/ l, whereas BOD_5 leaving the system is 8.2 mg / l. Suspended Solids entering the system are considerably very high (average 245 mg/l). However the system effects about 88 % reduction of the suspended solids. Finally total nitrogen coming into the system is 21.6 mg/l, comprised of 17.4 mg $NH4^{+}$- N/l and 4.2 mg/l organic nitrogen.

Table 4.2 - Design conditions versus actual operating conditions (average values)

Parameters	Design	Actual	Actual fraction of design
Daily flow m3/day	208,000	142,000	0.68
Sludge recycle rate Average daily flow , % average Peak , % flow	75 150		
Influent BOD mg/l	170	133	0.78
Effluent BOD mg/l	17	8.2	0.48
Influent total SS mg/l	200	245	1.23
Effluent total SS mg/l	30	29	0.97
MLSS mg/l	4000	3150	0.79
Aeration detention time (0) hrs	16.4	18	1.1
Sludge residence time (SRT) days	20 - 30	15 - 19	
Sludge volume index (SVI) ml/g		200	
Temperature C	15 - 30		
pH		7.65	

Table 4.3 Characteristics of Dammam Raw Sewage and Final Effluent

Parameters	Raw sewage	Final effluent
BOD	133	8.2
	245	29
pH	7.65	7.68
Dissolved Oxygen mg/l	0	5.6
Chlorides mg/l	1870	1394
Total nitrogen mg/l	21.6	1.73
Total jeldahl nitrogen mg/l	21.6	1.43
Ammonai mg/l	17.4	0.05
Nitrate mg/l	0	2.9

Chapter 5

METHODOLOGY

Dammam treatment facility was extensively sampled from May 13th to September 21st 1992. Individual Grab samples were collected from the influent, effluent before chlorination, and several locations in the aeration tank. The sampling program, designed to study the temporal variations, consisted of collecting weekly samples for four weeks, daily samples for five days, and hourly samples for one day (See Table 3.1). Samples were analyzed according to the procedures described by the standard method for the examination of water and wastewater (31). Methods used are : 420 A for total Kjeldahl, 419 D for ammonia nitrogen, 418 A for nitrate and nitrite nitrogen, 508 A for COD, 507 for BOD, and for suspended solids 209 D and 209E are used. Dissolved oxygen was also measured at numerous locations and at different depths in the ditch.

Chapter 6

RESULTS AND DISCUSSION

6.1 Performance Evaluation

6.1.1 Dissolved Oxygen (DO)Conditions .

During the initial study, dissolved oxygen was measured at a constant depth (0.5 m) and at deferent depths at four different locations in the carrousel reactor as shown in Figure 3.1. Table 6.1 lists the measured DO concentrations. As expected, the lowest concentration occurred at point 1 (0.6 mg/l) which is located near the aeration inlet (100 meter away from the first aerator) while the highest DO(4.5 mg/l) was at the effluent structure after the last aerator. In addition, the table shows significant variations in the oxidation ditch. As we get closer to the aeration zone, DO concentration gets higher. However , passing from the aeration zone into the channel, DO concentration decreases linearly. On the other hand , the table shows insignificant variations of DO with depths.

6.1.2 Treatment Efficiency Assessment

Dammam plant was monitored between the period of 13^{TH} May to

Table 6.1 Concentration of Dissolved Oxygen in Dammam Carrousel Plant, May 10 1992

Depth, meter	Dissolved oxygen concentration (mg/l) Locations			
	1	2	3	4
0.5	0.6	0.9	2.4	4.5
1.5	0.5	0.8	2.2	3.8
2.5	0.5	0.7	2.0	3.5
3.5	0.4	0.6	1.9	2.4

21^{ST} of September, 1992 to evaluate the plant performance, verify the hypothesis that nitrification and denitrification occur inside the aeration tank, and to model plant mathematically. The laboratory results of the tests carried on during the field study are shown on Tables 6.2 to 6.15. The operational data presented on those tables were collected based on weekly (Tables 6.2 to 6.5), daily (Tables 6.6 to 6.10), and hourly tests (Tables 6.11 to 6.15). The maximum effluent BOD_5 occurs on June 13^{th} and July 13^{th} with a concentration of 15 mg/ l . Moreover, the minimum effluent BOD_5 found at a concentration of 3.5 mg/l at 6:00a.m. of Sptember 21^{ST}. A profile of the range and average values of the operational data collected is illustrated on Table 6.16. The following summary of the overall operational illustrates the degree of treatment being obtained at Dammam plant.

High level of BOD_5 removals (over 93%) was obtained during the monitoring period with effluent BOD_5 ranging between 3.5 and 15 mg /l and averaging effluent at 8.2 mg/l. The long SRT used for this process was the reason behined achieving very low effluent BOD_5 concentrations.The Dammam carrousel system also achieved high level of suspended solids removals (around 88%) with an average effluent suspended solids at about 29 mg/l. Total effluent nitrogen concentrations averaged about 4.4 mg/l. The system activated over 88% total nitrogen removal, over 93% kjeldhal nitrogen (TKN) removal, and 99.7% ammonia removal.

Table 6.2 Field Study Results (Wedensday, May 13th 1992).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	39					39
Water temp. c	35					35
PH	7.46	6.96	6.92	7.0	7.1	7.67
DO (mg / l)	0	1.2	1.6	1.3	3.8	4.9
MLSS (mg / l)	209	2790	2590	2825	2870	29
VSS (mg / l)	150	2055	1835	2060	2090	25
Chlorides (mg/l)	2034	1378	1378	1312	1345	1312
BOD (mg/l)	115	75	50	45	35	15
COD (mg/l)	349.6	118.9	49	49	35	28
Grease &Oil						
Total Phosphate						
TKN (mg/l)	35	5.6	2.8	1.1	1.04	0.7
Ammonia (mg/l)	25.76	0.56	0.28	0.28	0.0	0
Nitrate (mg / l)	0	0.30	0.30	0.30	0.29	2.22
Nitrite (mg / l)	0	0.0	0.05	0.04	0.05	0

Table 6.3 Field Study Results(Wedensday May 20th 1992).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	36					36
Water temp. c	35					35
PH	7.57	7.02	6.96	7.00	6.96	7.54
DO (mg / l)	0	0.0	0.0	0.5	1.1	6.5
MLSS (mg / l)	145	2550	2730	2935	2830	14
VSS (mg / l)	95	1510	1610	1740	1585	10
Chlorides (mg/l)	1706	1378	1640	1476	1476	1476
BOD (mg/l)	120	70	55	45	39	12.5
COD (mg/l)	671.2	76.9	56	70	63	42
Grease &Oil						
Total Phosphate						
TKN (mg/l)	29.6	2.24	2.24	2.25	1.68	0.56
Ammonia (mg/l)	22.4	0.84	0.61	0.28	0.0	0
Nitrate (mg / l)	0	0.36	0.31	0.31	0.3	2.2
Nitrite (mg / l)	0	0.05	0.04	0.0	0.0	0.02

Table 6.4 Field Study Results (Wedensday June 24th 1992).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	39					39
Water temp. c	37					37
PH	7.57	7.03	7.03	7.05	7.06	7.47
DO (mg / l)	0	0.0	0.0	0.2	0.4	4.2
MLSS (mg / l)	75	2765	2745	2605	2725	8
VSS (mg / l)	29	1280	1245	1120	1095	6
Chlorides (mg/l)						
BOD (mg/l)	127	87.75	81.25	58.5	30	12
COD (mg/l)	377.6	118.9	132.9	76.9	74.2	63
Grease &Oil						
Total Phosphate						
TKN (mg/l)	21.68	1.93	1.86	1.33	0.7	0.35
Ammonia (mg/l)	16.88	0.42	0.40	0.056	0.084	0
Nitrate (mg / l)	0	0.44	0.4	0.38	0.38	2.94
Nitrite (mg / l)	0	0.0	0.0	0.0	0.0	0.1

Table 6.5 Field Study Results (Wedensday July 1st 1992).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	35					35
Water temp. c	36					36
PH	7.66	7.17	7.25	7.13	7.14	7.68
DO (mg / l)	0	0.0	0.0	0.6	1.6	7.2
MLSS (mg / l)	84	3800	3820	4000	4050	70
VSS (mg / l)	44	2210	2250	2500	2410	16
Chlorides (mg/l)						
BOD (mg/l)	101	69	49	36	23	5
COD (mg/l)	419.5	169.9	104.9	139.8	95.8	14
Grease &Oil	7					4
Total Phosphate	9.6	11.9	13.3	11.9	11.9	10.4
TKN (mg/l)	18.33	1.12	0.81	0.55	0.46	0.17
Ammonia (mg/l)	17.68	1.04	0.73	0.056	0.014	0.014
Nitrate (mg / l)	0	0.33	0.38	0.48	0.43	2.7
Nitrite (mg / l)	0	0.005	0.004	0.00	0.00	0.002

Table 6.6 Field Study Results (Sunday July 12th 1992).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	37					37
Water temp. c	37					37
PH	7.69	7.2	7.29	7.09	7.21	7.68
DO (mg / l)	0	2.1	2.3	2.5	2.4	5.2
MLSS (mg / l)						
VSS (mg / l)						
Chlorides (mg/l)						
BOD (mg/l)	143		84.5			7
COD (mg/l)						
Grease &Oil						
Total Phosphate mg/l						
TKN (mg/l)	15.3	2.25	1.5	0.95	0.8	1.1
Ammonia (mg/l)	14.7	0.66	0.29	0.18	0.07	0.05
Nitrate (mg / l)	0	0.43	0.44	0.45	0.55	3.2
Nitrite (mg / l)	0	0.01	0.05	0.015	0.02	0.1

Table 6.7 Field Study Results (Tuesday July 13th 1992).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	36					36
Water temp. c	36					36
PH	7.7	7.1	7.14	7.17	7.14	7.8
DO (mg / l)	0	0.5	0.4	0.7	1.7	4.9
MLSS (mg / l)	36	2870	3160	3510	3630	12
VSS (mg / l)	16	1860	2260	2670	2680	6
Chlorides (mg/l)						
BOD (mg/l)	105	85	80	65	40	15
COD (mg/l)	349.6	98	139.8	125.8	63	63
Grease &Oil						
Total Phosphate						
TKN (mg/l)	13.92	1.89	1.1	0.64	0.41	0.25
Ammonia (mg/l)	13.8	0.14	0.14	0.028	0.014	0.034
Nitrate (mg / l)	0	0.44	0.41	0.39	0.39	3.2
Nitrite (mg / l)	0	0.05	0.04	0.00	0.00	0.02

Table 6.8 Field Study Results (Wedensday July 14th 1992).

TYPE OF TEST	INFLUENT	AERATION TANK sAMPLING POINTS				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	39					39
Water temp. c	38					38
PH	7.86	7.21	7.17	7.18	7.20	7.9
DO (mg / l)	0	0	0	1.1	1.5	7
MLSS (mg / l)						
VSS (mg / l)						
Chlorides (mg/l)						
BOD (mg/l)	150		123.5	----	----	9.1
COD (mg/l)						
Grease &Oil						
Total Phosphate mg/l						
TKN (mg/l)	15.49	3.94	2.44	0.81	0.75	O.58
Ammonia (mg/l)	11.89	1.82	0.50	0.24	0.17	0.056
Nitrate (mg / l)	0	0.41	0.46	0.45	0.45	1.95
Nitrite (mg / l)	0	0.025	0.014	0.04	0.015	0.065

Table 6.9 Field Study Results (Wedensday July 15th 1992).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	36					36
Water temp. c	37.5					37.5
PH	7.58	7.16	7.18	7.2	7.38	7.73
DO (mg / l)	0	0.4	0.5	0.7	2.4	7.1
MLSS (mg / l)						
VSS (mg / l)						
Chlorides (mg/l)						
BOD (mg/l)	143		117	----	---	7.5
COD (mg/l)						
Grease &Oil						
Total Phosphate						
TKN (mg/l)	23.28	3.04	2.23	1.39	0.23	0.17
Ammonia (mg/l)	19.5	0.78	0.084	0.084	0.064	0.056
Nitrate (mg / l)	0	0.45	0.48	0.50	0.65	2.4
Nitrite (mg / l)	0	0.01	0.015	0.025	0.025	0.085

Table 6.10 Field Study Results (Thursday July 16th 1992).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	35					35
Water temp. c	37.5					37.5
PH	7.71	7.07	7.08	7.05	6.96	7.72
DO (mg / l)	0	0.90	0.80	1.7	3.0	7.3
MLSS (mg / l)						
VSS (mg / l)						
Chlorides (mg/l)						
BOD (mg/l)	175	90	75	60	50	6.5
COD (mg/l)						
Grease &Oil						
Total Phosphate						
TKN (mg/l)	20.85	3.7	0.93	0.3	0.19	0.99
Ammonia (mg/l)	15.35	0.448	0.672	0.17	0.056	0.056
Nitrate (mg / l)	0	0.43	0.45	0.46	0.49	2.54
Nitrite (mg / l)	0	0.008	0.08	0.01	0.005	0.105

Table 6.11 Field study Results (Sep.21st 1992, 6:00 a.m.).

TYPE OF TEST	INFLUENT	AERATION TANK sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	24					24
Water temp. c						
PH	7.58	7.32	7.55	7.37	7.42	7.75
DO (mg / l)	0	0.0	0.2	1.1	1.5	4.5
MLSS (mg / l)						
VSS (mg / l)						
Chlorides (mg/l)						
BOD (mg/l)	123.5		84.5	---	-	3.5
COD (mg/l)						
Grease &Oil						
Total Phosphate mg/l						
TKN (mg/l)	20.83	5.15	3.25	2.1	1.91	1.79
Ammonia (mg/l)	14.39	0.11	0.0	0.0	0.0	0
Nitrate (mg / l)	0	0.39	0. 38	0.4	0.41	3.8
Nitrite (mg / l)	0	0.015	0.08	0.04	0.05	0.04

Table 6.12 Field Study Results (Sep.21st 1992, 10:30 a.m.).

TYPE OF TEST	INFLUENT	AERATION TANK sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	32					32
Water temp. c	37					37
PH	7.84	7.37	7.37	7.42	7.45	7.64
DO (mg / l)	0	0.0	0.0	0.9	1.6	4.7
MLSS (mg / l)						
VSS (mg / l)						
Chlorides(mg/l)						
BOD (mg/l)	143		75			7
COD (mg/l)						
Grease &Oil						
Total Phosphate mg/l						
TKN (mg/l)	22.51	6.46	4.5	2.35	1.9	1.23
Ammonia (mg/l)	17.3	0.0	0.056	0.0	0.0	0
Nitrate (mg / l)	0	0.45	0.47	0.48	0.48	3.48
Nitrite (mg / l)	0	0.015	0.016	0.04	0.06	0.055

Table 6.13 Field Study Results (Sep.21st 1992, 3:00 p.m).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	37					37
Water temp. c	37					37
PH	7.67	7.42	7.42	7.38	7.4	7.62
DO (mg / l)	0	0.0	0.0	0.8	2.1	5.8
MLSS (mg / l)						
VSS (mg / l)						
Chlorides(mg/l)						
BOD (mg/l)	150		94			5.2
COD (mg/l)						
Grease &Oil						
Total Phosphate mg/l						
TKN (mg/l)	25.31	5.71	5.71	2.91	2.75	2.07
Ammonia (mg/l)	19.94	2.29	2.02	0.11	0.11	0
Nitrate (mg / l)	0	0.38	0.39	0.44	0.47	3.57
Nitrite (mg / l)	0	0.04	0.08	0.02	0.02	0.21

Table 6.14 Field Study Results (Sep.21st 1992, 7:30 p.m.).

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	31					31
Water temp. c	35					35
PH	7.54	7.28	7.34	7.33	7.39	7.65
DO (mg / l)	0	0.0	0.0	0.4	1.5	4.2
MLSS (mg / l)						
VSS (mg / l)						
Chlorides(mg/l)						
BOD (mg/l)	130	85	75	60	55	9
COD (mg/l)						
Grease &Oil						
Total Phosphate mg/l						
TKN (mg/l)	21.06	7.79	3.92	6.38	4.26	3.81
Ammonia (mg/l)	17.08	2.39	1.01	0.15	0.056	0
Nitrate(mg / l)	0	0.36	0.37	0.39	0.40	3.1
Nitrite (mg / l)	0	0.03	0.08	0.03	0.05	0.42

Table 6.15 Field Study Results (Sep.21st 1992, 12:00 p.m.)

TYPE OF TEST	INFLUENT	AERATION TANK Sampling points				EFFLUENT
		P1	P2	P3	P4	
Air temp. c	29					29
Water temp. c	35					35
PH	7.62	7.37	7.27	7.32	7.35	7.68
DO (mg / l)	0	0.0	0.0	0.7	1.7	4.6
MLSS (mg / l)						
VSS (mg / l)						
Chlorides(mg/l)						
BOD (mg/l)	136		72			5
COD (mg/l)						
Grease &Oil						
Total Phosphate mg/l						
TKN (mg/l)	19.71	4.91	1.68	2.73	1.23	6.27
Ammonia (mg/l)	16.41	0.0	0.03	0.0	0.0	0
Nitrate (mg / l)	0	0.36	0.45	0.45	0. 45	3.3
Nitrite (mg / l)	0	0.02	0.06	0.02	0.02	0.255

Table 6.16 Summary of The Field Study Results For Dammam Carrousel (Range, Average values, And Percent Removals)

TYPE OF TEST	INFLUENT		AERATION TANK SAMPLING POINTS								EFFLUENT		Percent removal based on
			POINT 1		POINT 2		POINT 3		POINT 4				average values
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	
Air temp. c	24-39	34.6										34.6	
Water temp. c	22-38	33											
PH	7.46- 7.86	7.65	6.96-7.42	7.19	6.92-7.55	7.2	6.96-7.42	7.2	6.93-7.45	7.2	7.47-7.9	7.68	
DO (mg / l)	0	0	0 - 2.1	0.4	0 - 2.3	0.6	0 - 2.5	1.3	1.5 - 4.0	2.4	4.2 - 7.3	5.6	
Total SS mg/l		245										29	88.2
MLSS (mg / l)			2550-3800	2955	2590-3820	3009	2605-4000	3175	2725-4050	3217			
MLVSS (mg / l)			1510-2215	1784	1245-2260	1839	1120-2670	2018	1095-2415	1881			
Chlorides(mg/l)	1706-2034	1870	1378-1378	1378	1345-1640	1509	1312-1476	1394	1345-1476	1410	1312-1394	1394	
BOD (mg/l)	101-175	132.96	69-87.8	77.35	49-123.5	79	36-65	50	23-40	33.4	3.5-15	8.2	93.8
Oil & grease		7										4	
Total phosphate mg/l		9.6		11.9		13.3		11.9		11.9		10.4	
Total nitrogen mg/l		21.6										4.38	92
TKN (mg/l)	13.9-35	21.6	1.1-7.8	3.9	0.8-6.7	2.5	0.4-6.38	1.75	0.28-4.26	1.48	0.17-3.8	1.43	93
Ammonia (mg/l)	11.89-25.76	17.4	0-2.39	0.82	0-2.02	0.45	0-0.84	0.14	0-0.67	0.06	0 - 0.056	0.05	99.7
Nitrate (mg / l)	0 - 0	0	0.2 -0.45	0.4	0.3-0.48	0.44	0.3-0.5	0.45	0.3-0.65	0.49	1.9-3.8	2.9	
Nitrite(mg / l)	0 - 0	0	0-0.04	0.02	0-0.08	0.02	0-0.04	0.035	0-0.06	0.04	0-0.42	0.11	

The variations in BOD_5, Ammonia, TKN, Nitrate, and Nitrite concentrtion during the days of testing are shown on Figures 6.1 to 6.6. Figure 6.7 illustrates weekly, daily and hourly variation of effluent BOD_5, SS,and TKN concentrations. Very low effluent NH^+_4 - N and NO_2^- N concentrations in the range of 0.05 - 0.1 mg/l were detected and are therefore not shown to maintain clarity. As demonstrated by Figure 6.7, weekly variation test showed that SS and BOD varied appreciably from one week to the other. The maximum weekly SS was 70 mg/l and the minimum was 15 mg/l, while BOD_5 maximum and minimum values were 15 and 5 mg/l respectively. On the other hand, TKN and nitrate variations were negligable. Moreover, Ammonia and nitrite were hardly found in the effluent.

With respect to daily effluent observation, Figure 6.7 shows insignificant variation in SS concentration during the first four days (an average of 27 mg/l). However, a jump to 37 mg/l occured on July 16th, the last day of the week, as a result of the relatively high flow rate on that day. Effluent BOD_5 concentrations were almost constant at 5mg/ l throughout the study except for July 13th when the BOD_5 increased to 15 mg / l. Ammonia and nitrite concentrations were too low to notice any significant fluctuations. Finally, no appreciable variation in effluent nitrate concentration was observed.

Also, Figure 6.7 shows clear hourly variations in SS with Minimum

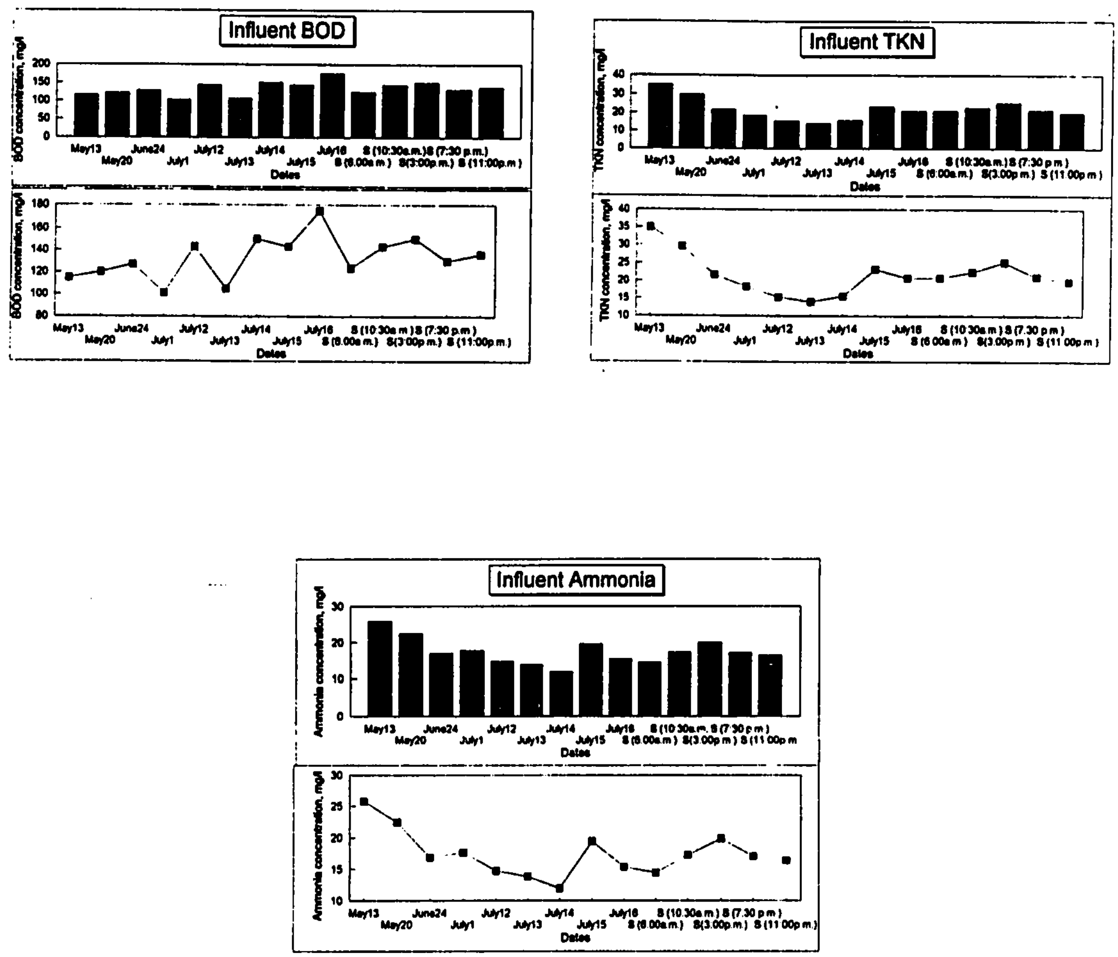


Figure 6.1 Variation of influent BOD, TKN, and NH4, concentrations with time

Note: S= September 21st

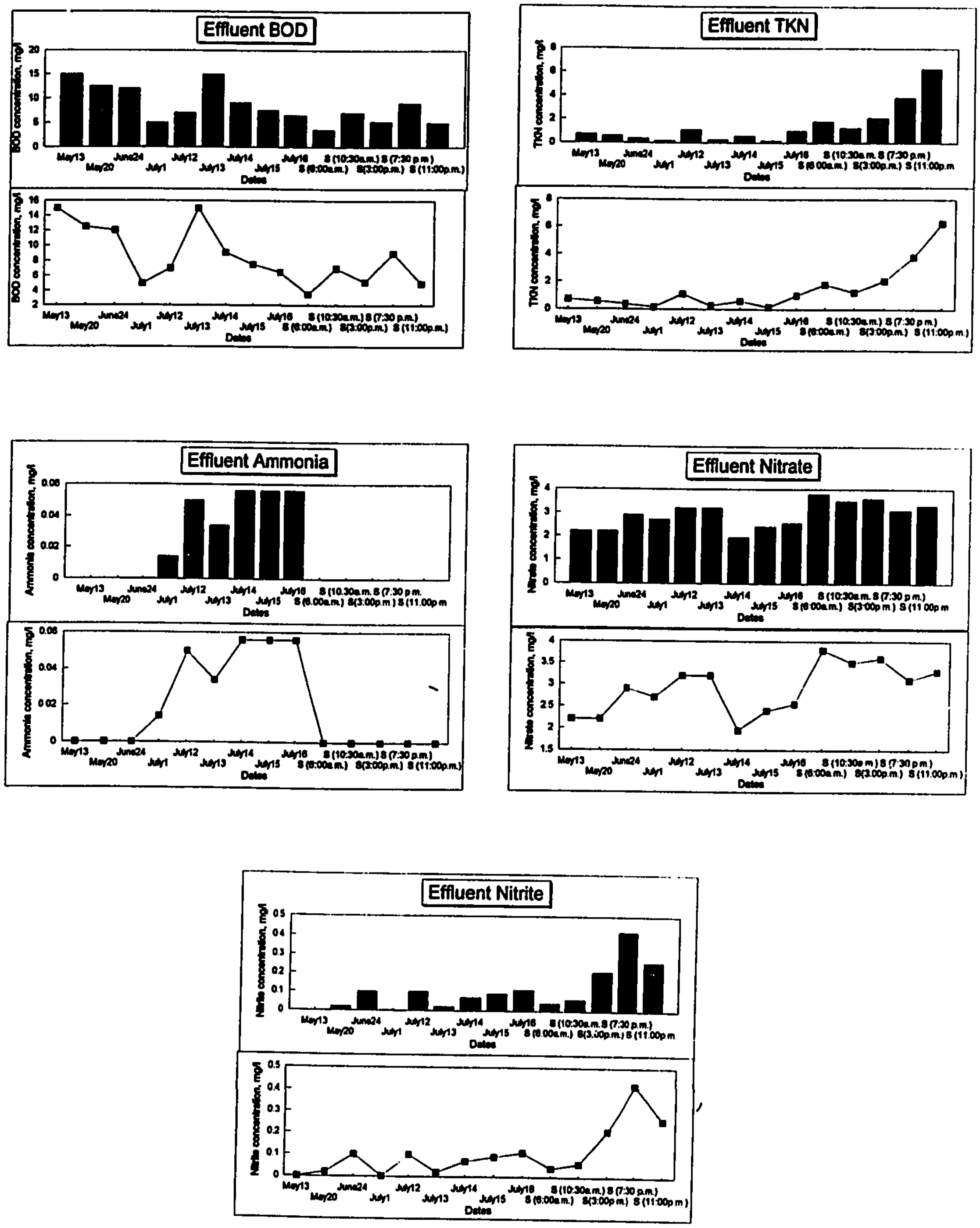


Figure 6.2 Variation of effluent BOD, TKN, NH4, NO3, and NO2 concentrations with time

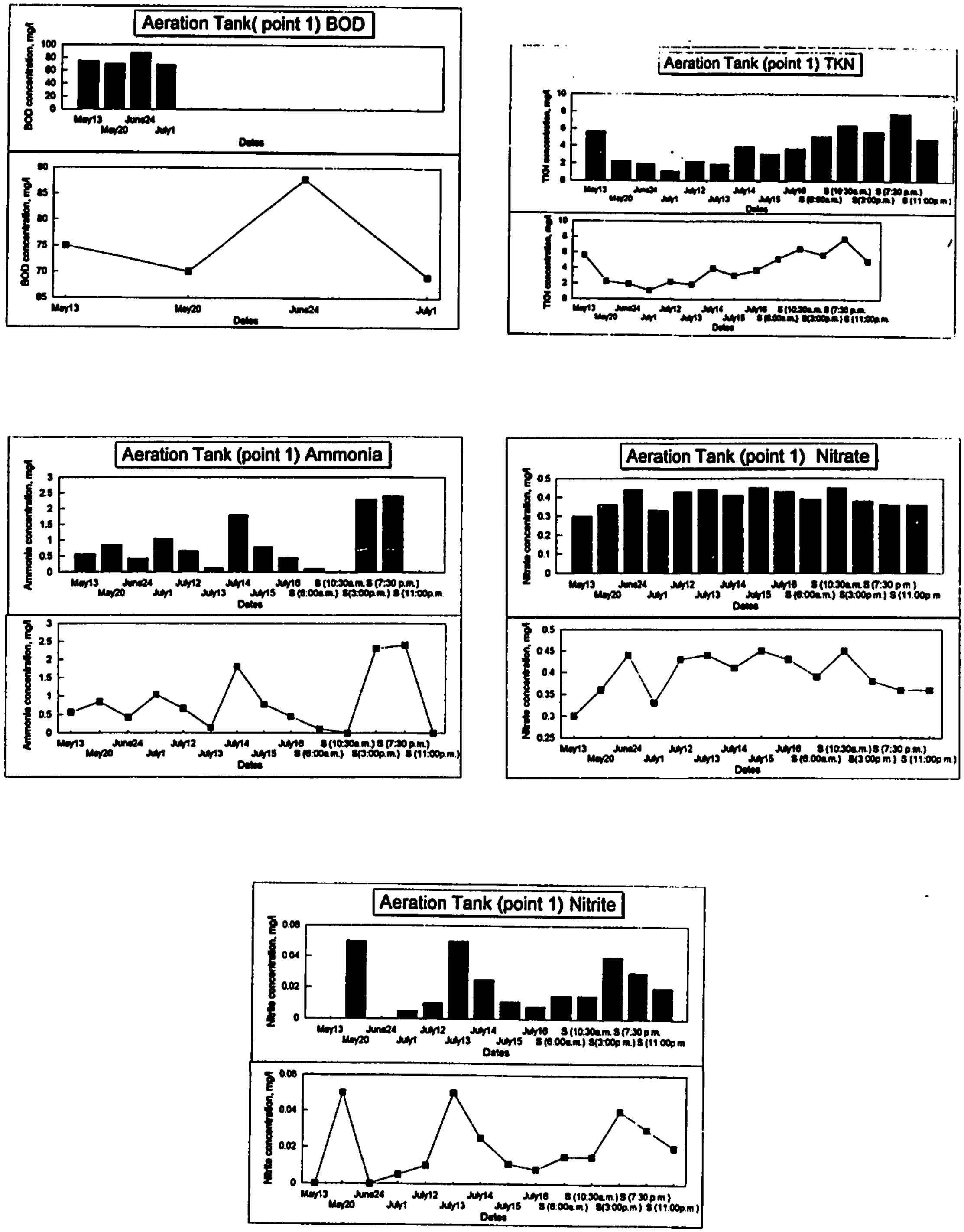


Figure 6.3 Variation of Point (1) BOD, TKN, NH4, NO3, and NO2 concentrations with time

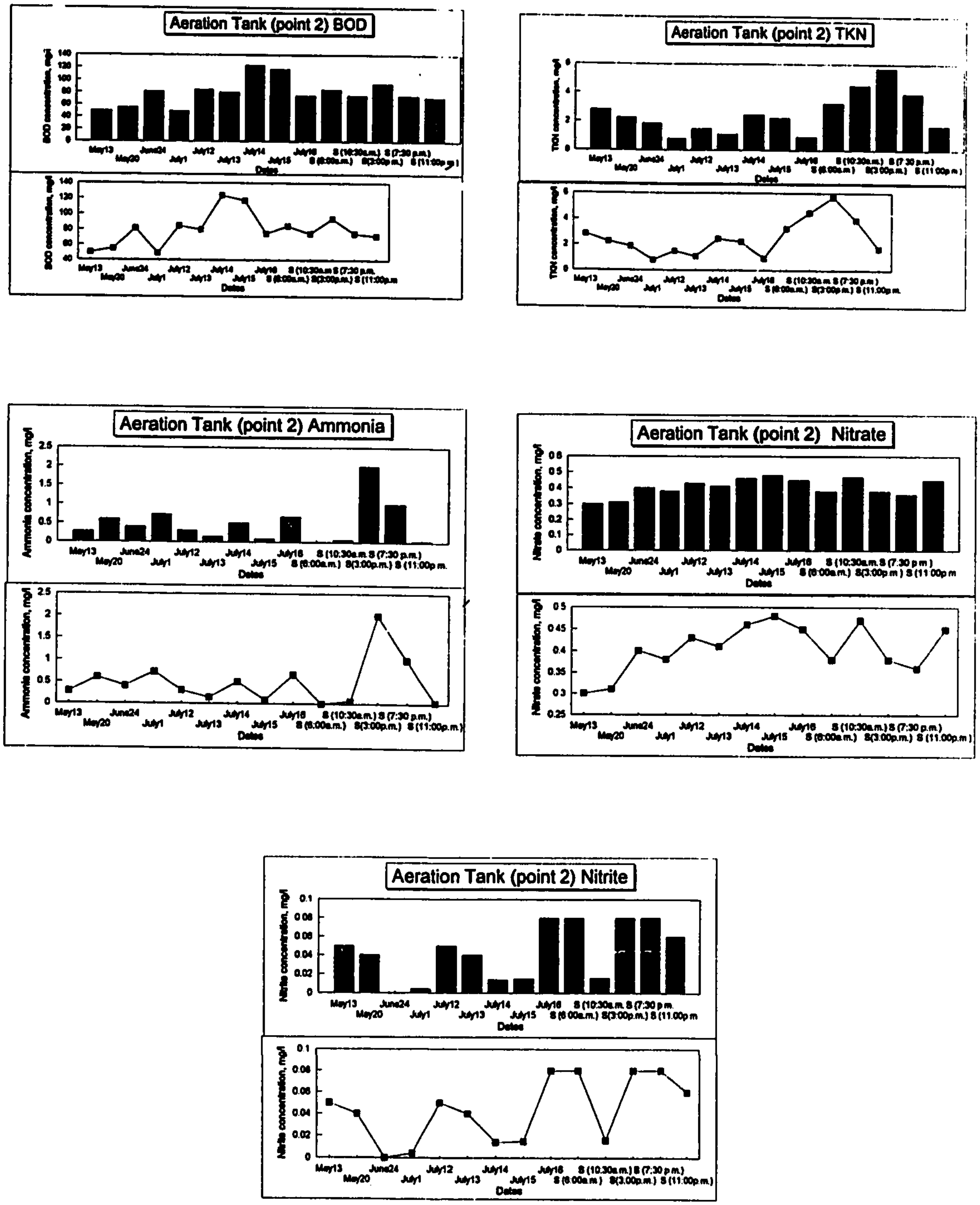


Figure 6.4 Variation of point (2) BOD, TKN, NH4, NO3, and NO2 concentrations with time

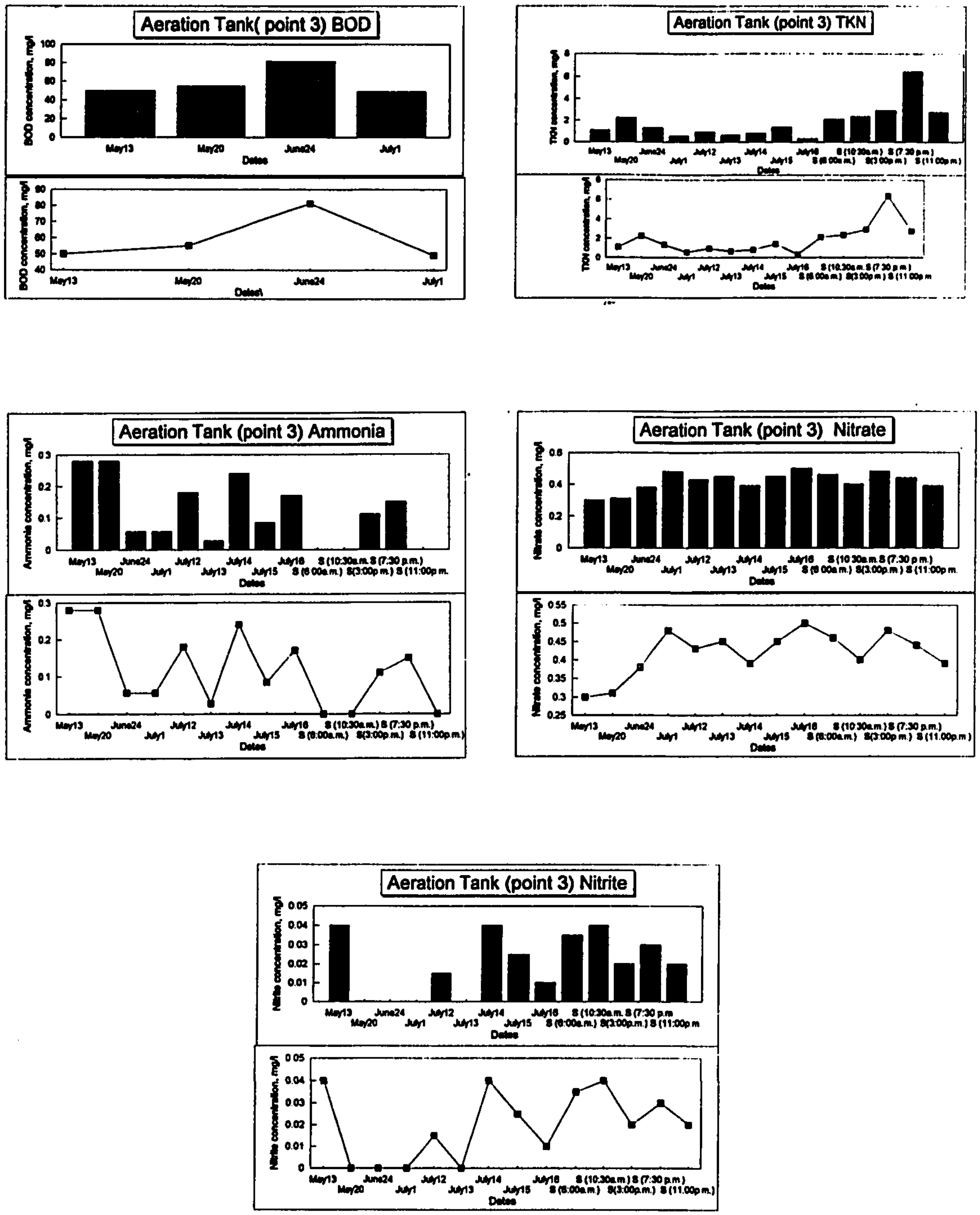


Figure 6.5 Varaition of Point (3) BOD, TKN, NH4, NO3, and NO2 concentrations with time

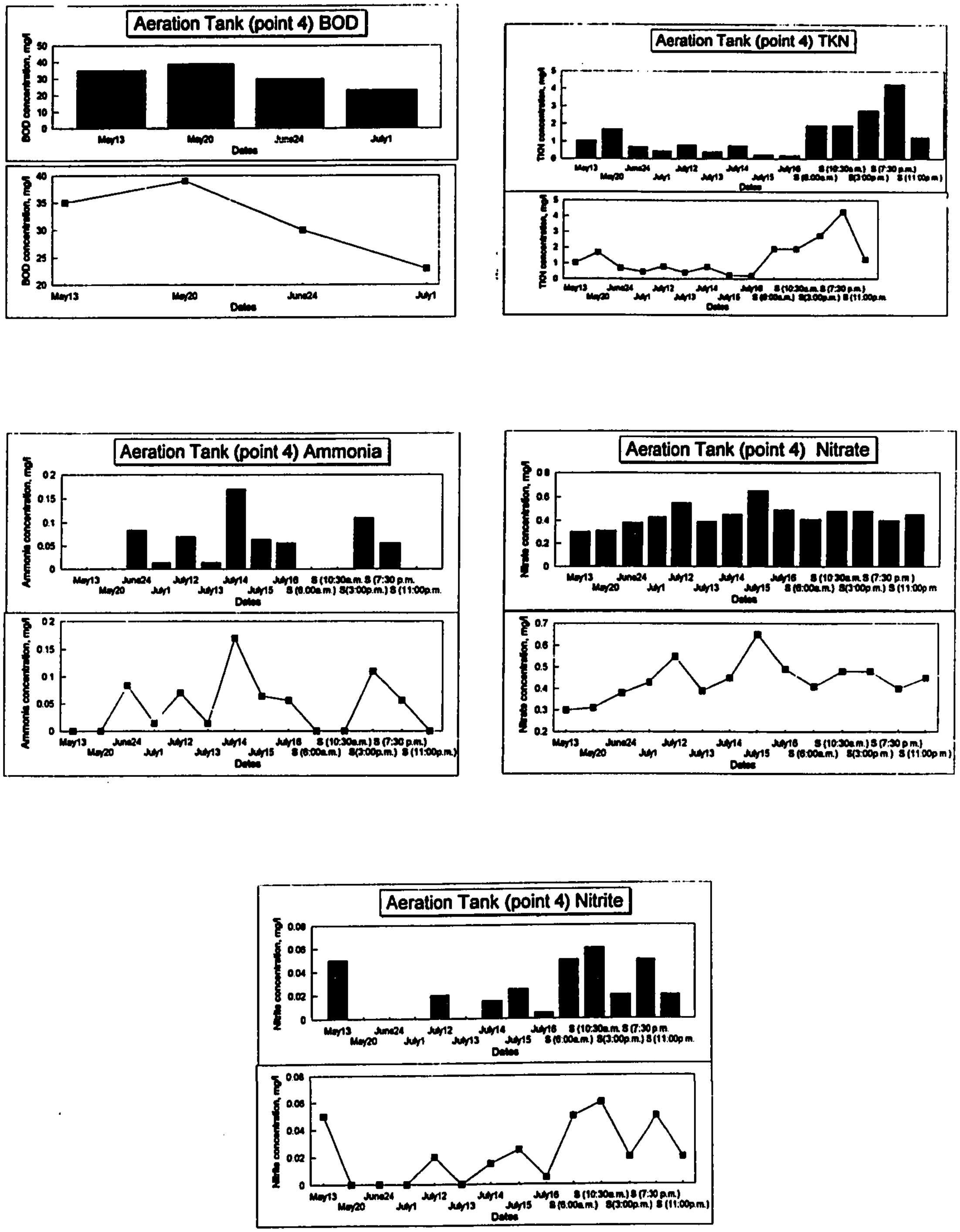


Figure 6.6 Variation of Point (4) BOD, TKN, NH4, NO3, and NO2 concentrations with time

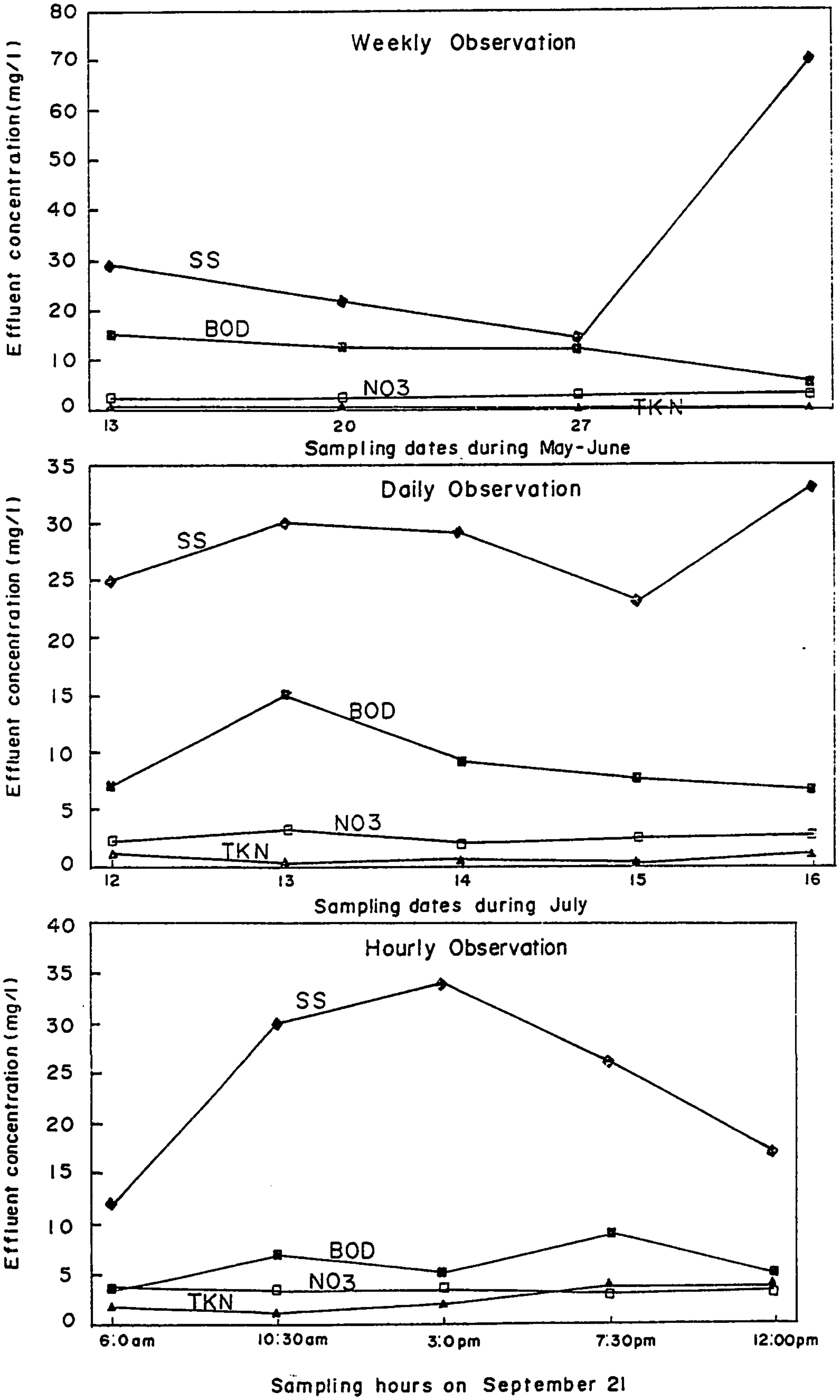


Fig. 6.7 Weekly, Daily, and Hourly Effluent Variations

SS (10 mg/l) reported at 6:00 a.m. and maximum SS (35 mg/l) reported at 3:00 p.m. . BOD_5 varied between 3.5 mg/l recorded at 6:00 a.m. and 9 mg/l recorded at 7:30 p.m. Ammonia and nitrite concentrations were negligible while hourly nitrate variations were insignificant. Figure 6.8 demonsrte weekly and daily MLVSS concentration. Weekly MLVSS ranged from 1183 mg/l to 2308 mg/l while daily MLVSS ranged from 2150 mg/l to 2410 mg/l.

6.1.3 Evaluation Of Nitrogen Removal By Nitrification-Denitrification

Denitrification occurs when the bacteria (facultative heterotrophic type) of the process use oxygen from the nitrate, thereby reducing the nitrate to nitrogen gas. Denitrification rate depends on nitrification (i.e. at high nitrification, high nitrogen removal will be achieved). Dammam process achieved very high nitrification (99.7 % Ammonia removal). To evaluate the process denitrification, a mass balance on nitrogen can be made which states that the influent TKN load is equal to the effluent TKN load plus effluent nitrate load and sludge nitrogen load will be utilized. This can be represented by the following equation :

$$Q * TKN_{in} = Q * TKN_{out} + Q * NO_{3\ out}^{-} + Q * NO_{2\ out}^{-} + 0.12 * Q_{Slu} * X_{SLu} \qquad (6\text{-}1)$$

where, Q = influent or effluent flow rate , m^3 / day

TKN_{in} = influent TKN concentration , mg / l

TKN_{out} = effluent TKN concentration , mg / l

0.12 = mass fraction of nitrifier in sludge

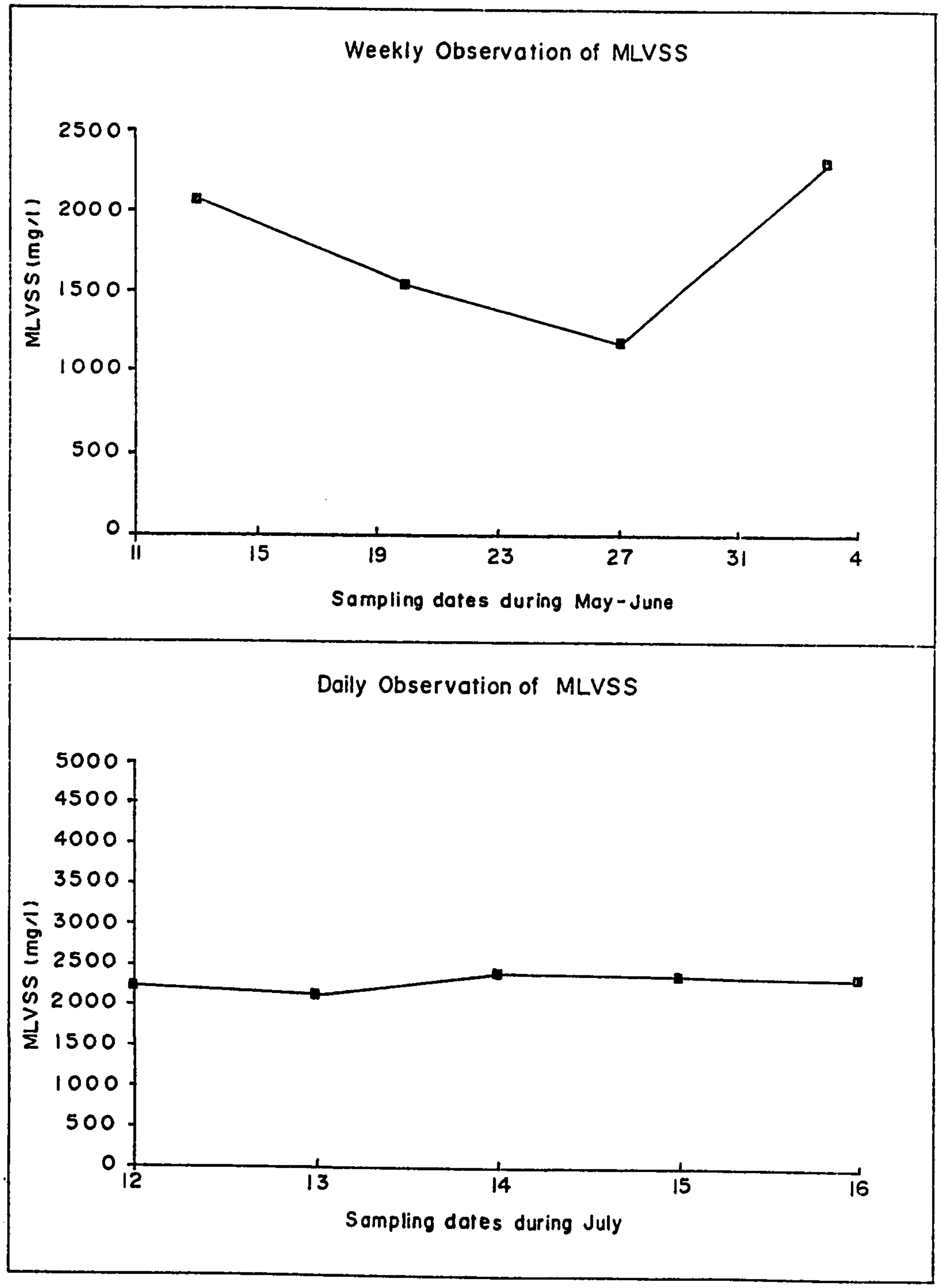


Fig. 6.8 Weekly and Daily MLVSS Variation

$NO_3^-{}_{out}$= effluent NO3$^-$ concentration , mg / l

$NO_2^-{}_{out}$ = effluent NO_3^- concentration , mg/l

Q_{Slu} = sludge wastage rate, kg/ day

X_{Slu}= concentration of volatile suspended solids in return sludge ,mg / l

It must be emphasized that the influent nitrates and nitrites were negligible (Table 6.16) and thus need not to be included in the mass balance.

Table 6.17 shows a summary of the percentage of nitrogen removal by various means including nitrification -denitrification at peak, average, and minimum flow conditions as well as, peak, average, and minimum nitrogen loading conditions. From Table 6.17, based on the average value (not taking into account the minimum load value), The results indicate that 12.5% of the influent nitrogen remained in the effluent and that 48% of the influent nitrogen was present in the waste sludge. Therefore denitrification to N_2 accounted for about 40% of the nitrogen removal. It is apparent that nitrification and denitrification increased with flow and nitrogen load. Nitrification and denitrification ranged from 30.9 to 55.8% and 20 to 48% respectively at peak and minimum flow conditions. With respect to load, nitrification and denitrification varied from 40.2 - 55 %, and 27 - 49.2 % between average and maximum nitrogen loading conditions. The relatively low denitrifications efficiency reported in this study is attributed to the relatively high DOs in the system. Data presented in Table 6.1 points to the

Table 6.17 Nitrogen Removal by Nitrification-Denitrification Under Several Conditions

Conditions	TKN mg/l	Nitrogen(in) = Q (TKN)in kg/day	Nitrogen (out) = Q (TKN)out + Q (NO3)out + 0.12 Qsl * Xsl			% Nitrification	% Rmoval by Nitrification-Denitrification
			Q (TKN)out	Q (NO3)out	0.12 Qsl *Xsl		
Peak flow (149270 m3/day)	29.6	4418.4	83.6	331.4	1870	55.8	48.3
Average flow (141000 m3/day)	27.5	3877.5	291.9	310	1618	50.7	42.7
Minimum flow (132155 m3/day)	18.3	2422.4	22.5	264	1652	30.9	20
Maximum load (kg/day)	35	4982	99.6	313	2116.3	55.5	49.2
Average load (kg/day)	21.6	3102	49.3	408.9	1809	40.2	27
Minimum load (kg/day)	13.9	2078	25.4	291.1	1693	17.3	3.3

absence of alternate oxic/anoxic zones necessary for denitrification. Actually anoxic conditions appear to prevail only between the inlet and first aerator. Although denitrifications has been reported to in flocs occur at 0.3-0.8 mg/l DO (27) such flocs preponder at very high MLVSS (6000 mg/l) as compared to 3000 mg/l MLVSS reported here. Figure 6.9 depicts that the percentage nitrification and denitrification at various flow and nitrogen loading conditions, is a linear function of the influent TKN.

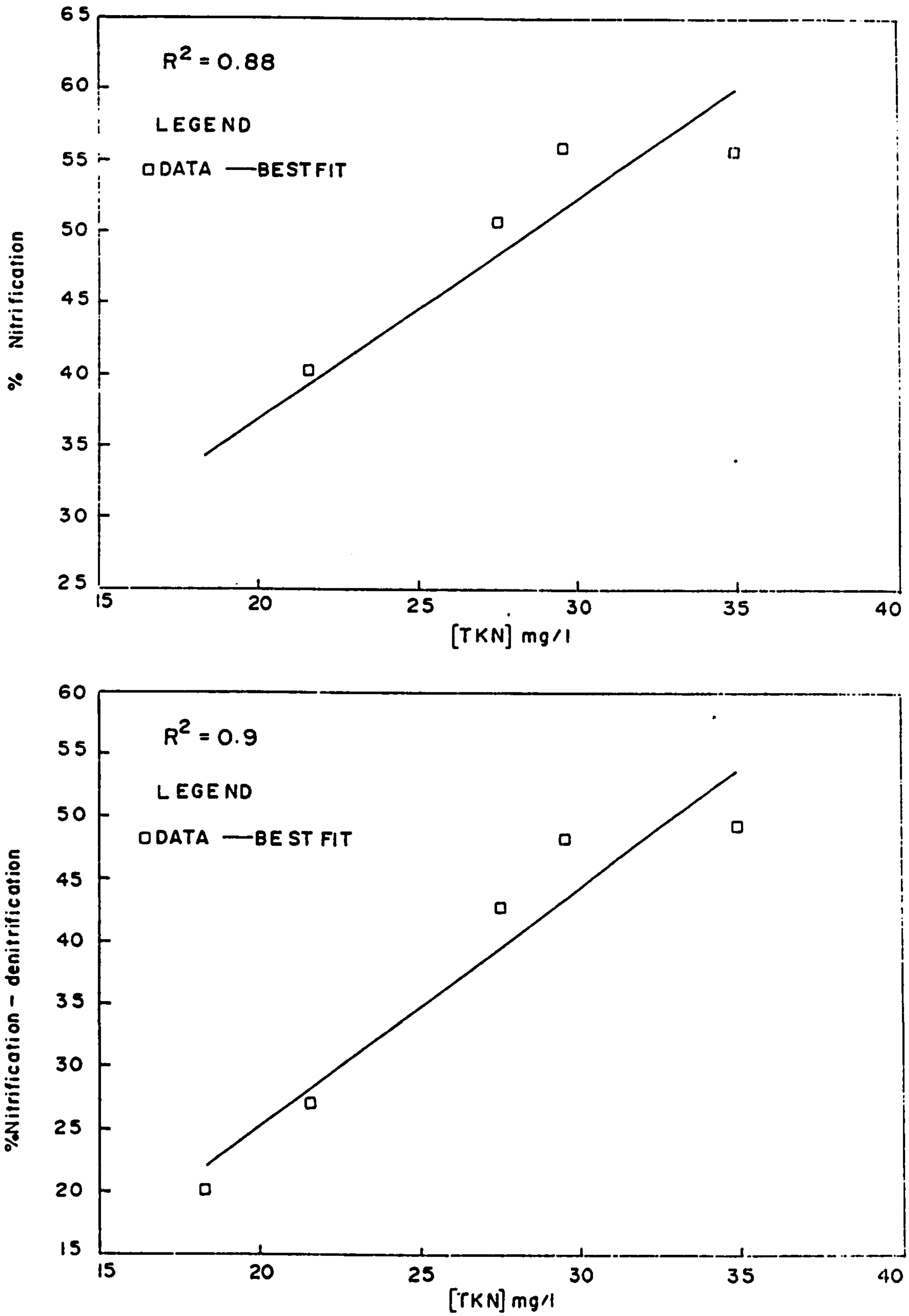


Fig. 6.9 Relationship Between Percentage Nitrification and Denitrification and Influent TKN

Chapter 7

MODELING DAMMAM CARROUSEL SYSTEM

In order to evaluate the data obtained from this study , the kinetic parameters of the system must be determined . Such a determination will give a consistent and valuable basis for optimizing design and operation of Dammam carrousel treatment system.

Several kinetic expressions have been proposed to describe the nitrification process . The most commonly used one is postulated by Monod .

$$dS/dt = -kXS/(K_s + S) \tag{7.1}$$

Where,

ds/dt = rate of substrate utilization , M_S/m^3. day

k = maximum rate of substrate utilization , $M_S M_X^{-1}$ /day

K_S= half velocity constant , M/m^3

S = concentration of growth limiting substrate in solution , M/m^3

Dammam carrousel system is mainly a plug flow reactor . Modeling it mathematically is difficult . However to come up with a useful kinetic model , one can follow the assumption of constant concentration postulated by Lawernce and McCarty (32). The Monod half velocity constant K_S is affected by various parameters. Downing and co - workers (11) estimated the dependence of K_S for ammonia oxidation on temperature(^{0} C) to follow:

$$K_S= 10^{0.051T-1.158} \qquad (7.2)$$

Shammas (33) , in his study found a significant interaction between , pH, temperature, MLVSS, and K_S. Temperature and pH affect K_S in away that depend on the biomass concentration .The result of his study showed that at a temperature of 10,17,25, and 33C ° and at a constant pH and MLVSS (7. 7 and 3200 mg /l respectively) , K_S values for ammonia oxidation were3, 2.2, 12, and 12 mg/l respectively. Pointer (34) also reported that K_S value for ammonia nitrogen oxidation varied from 1.0 mg/l at 20 C° to 3.5 and 10 mg /l at 25C° and 30 C°,respectively. For BOD, K_S value ranges between 20 and 100 mg/l at 20 C° (1 0). By comparison, the K_S value for Dammam carrousel must be very high since the average temperature during the period of study was 34.6 ^{0}C , the average pH was 7.7 , and the MLVSS was 3150 mg/l , and thus the substrate utilization rate will be first order in substrate concentration as given by:

$$dS/dt = kXS/K_S \qquad (7.3)$$

Furthermore the average MLVSS at the various sampling locations presented in Table 6.16 simply suggests minimal variability in MLVSS throughout the reactor .

Thus equation (7.3) reduces to :

$$dS/dt = PS \tag{7.4}$$

Where ,

$$P = kX/K_S \tag{7.5}$$

Integrating first order equation (7.4) , rate expression for a plug flow system yeilds:

$$Ln\ S_e / S_o = -Pt \tag{7.6}$$

Where, S_o and S_e respectively denote the influent substrate and substrate concentration at any point to which the travel time t. Thus a plot of ln S_e/S_o versus t should yeild a straight line with slope of -P .

Determination of System Biokinetic Constants

Figure 7.1 and 7.2 depict the graphical representation of equation (7.6) for various conditions of flow and BOD load respectively. The conformance of the data to the first order kinetic model is quite conspicuous. The same agreement is also observed for the ammonia data presented in Figures 7.3 and 7.4. The values of kX/K_S calculated from the aforementioned plots are presented in respective plots along with the coefficients of determination (R^2) . The high values of R^2 corroborate the description of system performance by first order kinetic model for BOD , and ammonia.

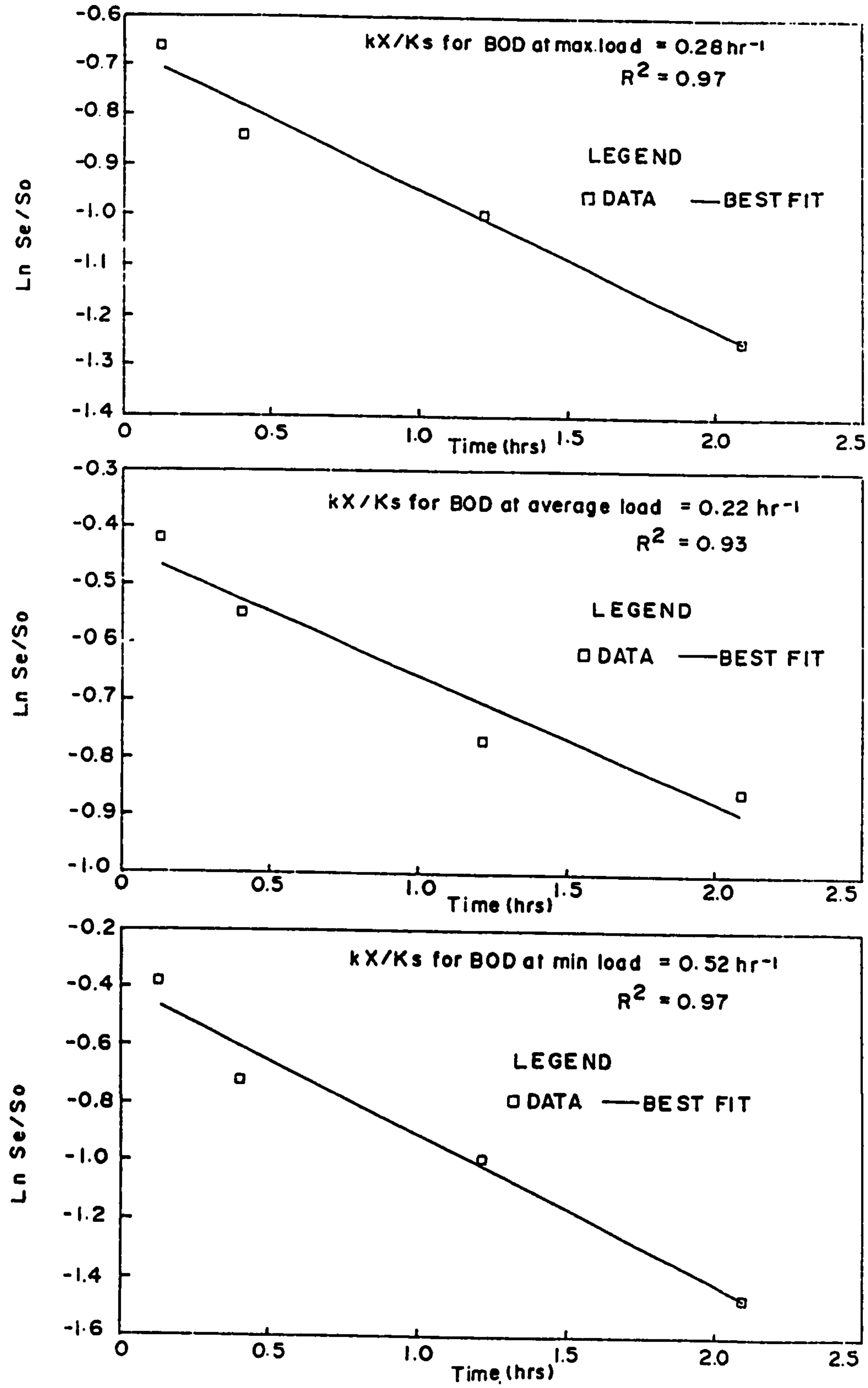


Fig. 7.1 Linearized BOD Temporal Profile at Various Loadings

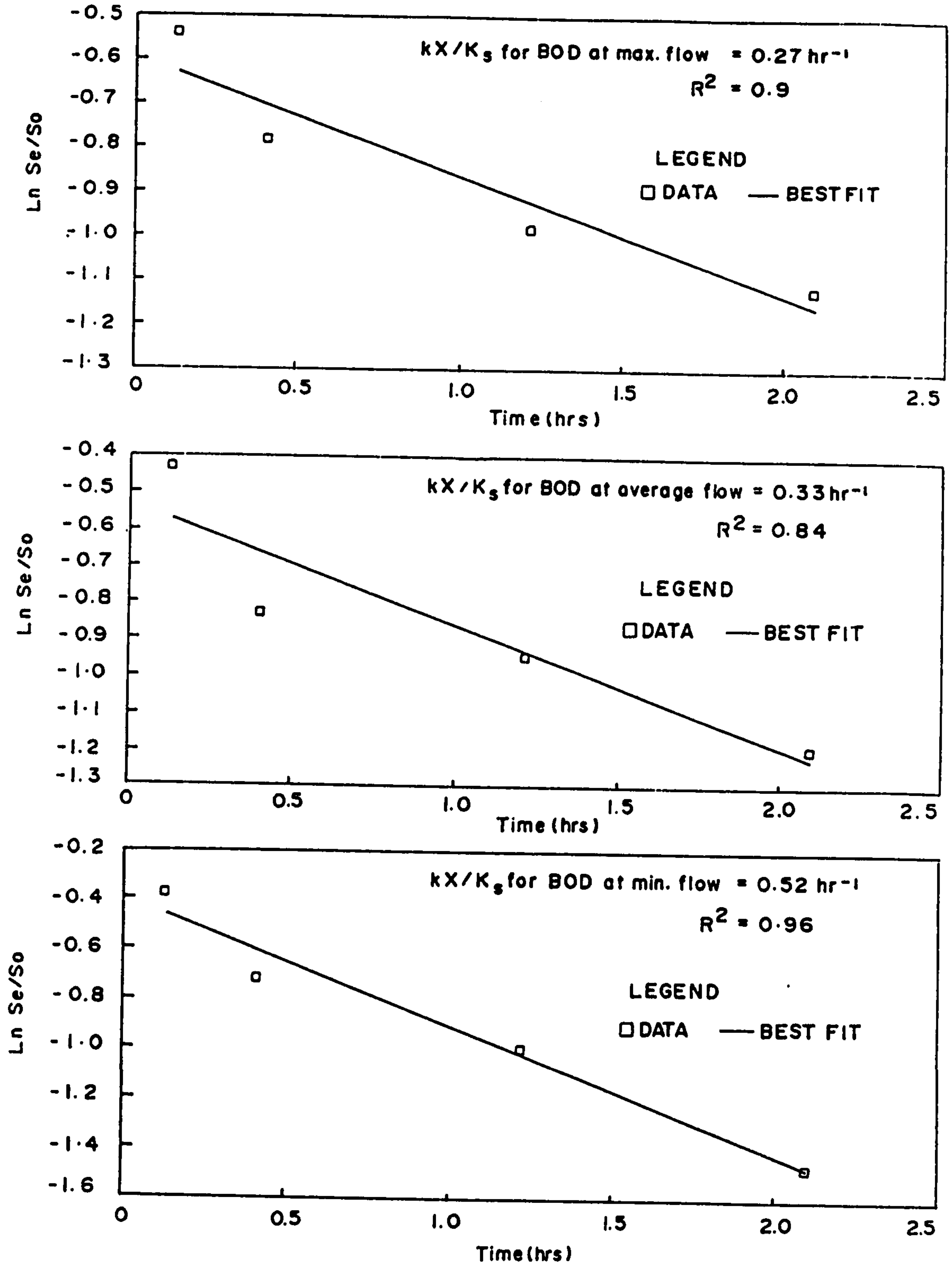


Fig. 7.2 Linearized BOD Temporal Profile at Various Flows

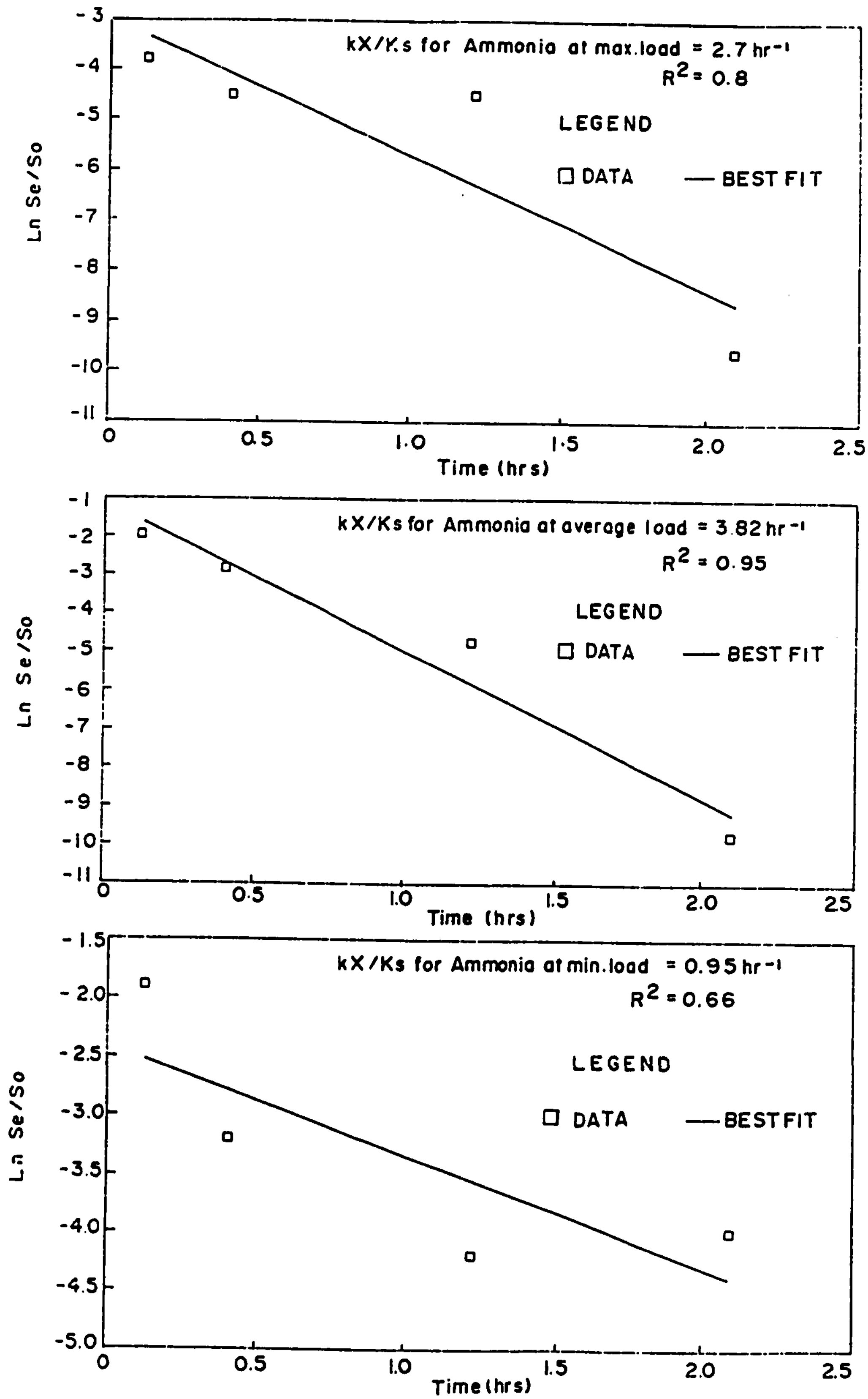


Fig. 7.3 Linearized Ammonia Temporal Profile at Various Loadings

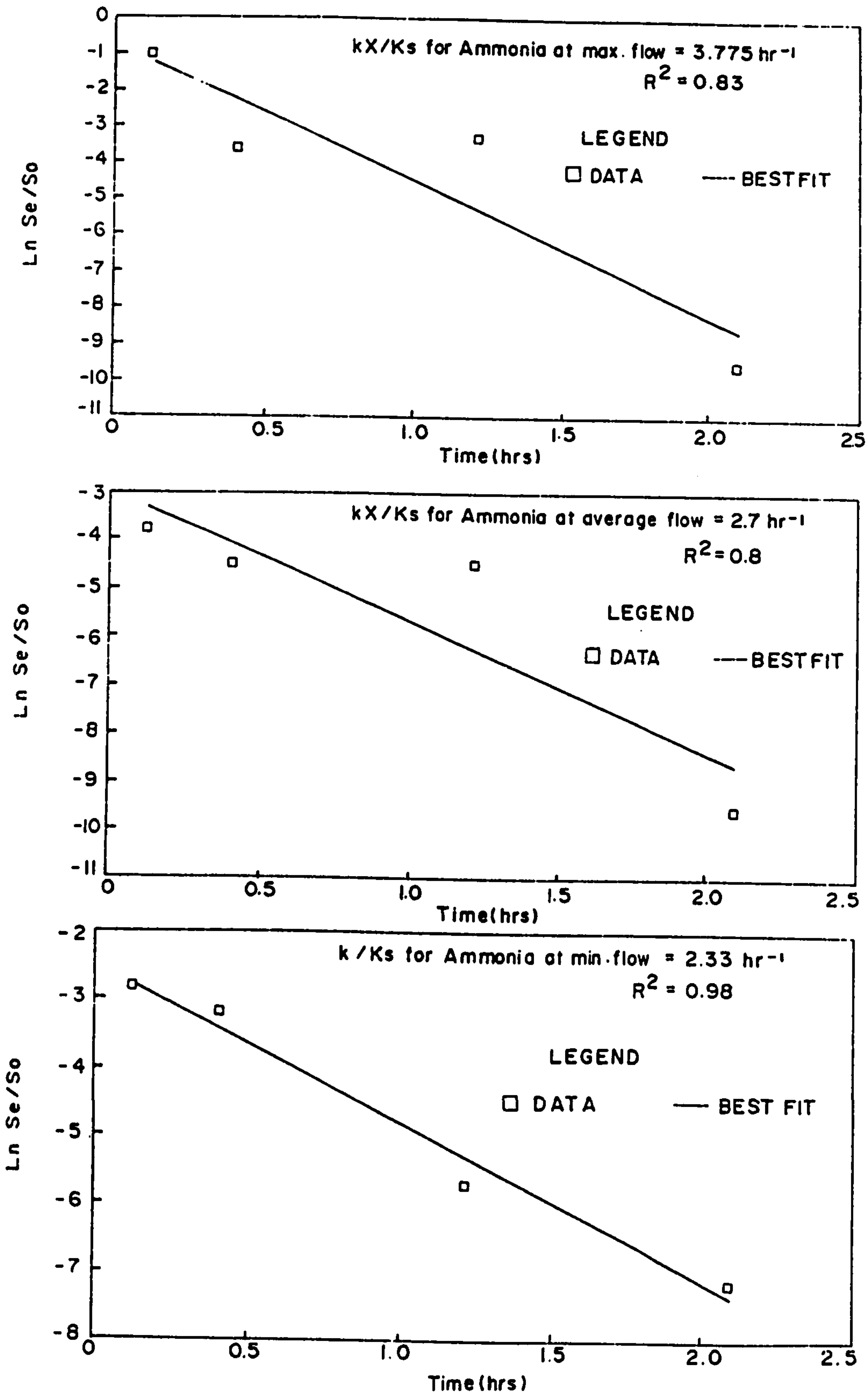


Fig. 7.4 Linearized Ammonia Temporal Profile at Various Flows

Although the plant data dose not permit the independent determination of k and K_S, the specific first order rate coefficient i. e. per unit biomass can be assessed . It is reasonable to assume that the average concentration of MLVSS in the plug flow carrousel system following first order kinetics is given by the log mean of the MLVSS concentration at the inlet and outlet of the system. Thus a plot of first order rate coefficient (kX / K_S) versus the log mean MLVSS concentrations should be linear with a slope of (k / K_S). The MLVSS comprised of heterotrophs and nitrifiers. The ratio of nitrifiers to heterotrophs corrssponding to an influent BOD_5 : TK N ratio of 5 is equal to 0.054 (10). Therefore, the concentrations of hetrotrophs and nitrifiers can be estimated. Figure 7.5 (a) and (b) depicts the relationship between the first order rate constant and the concentration of nitrifiers respectively. The k/K_S value of 0.0113 L/mg VSS-d corresponding to the specific first-order rate constant for BOD removals below the range of 0.02-0.4 derived from Metcalf and Eddy, 1991(10). Two possible explanation are postulated, the relatively low influent BOD_5 decreases the overall specific utilization rate, and secondly BOD removal by denitrification as well as proportioning the MLVSS by the ratio of oxic zones to anoxic zones in the ditch have not been accounted. On the other hand, the specific first-order rate constant for ammonia oxidation of 1.67 L/mg VSS-d is within the range of

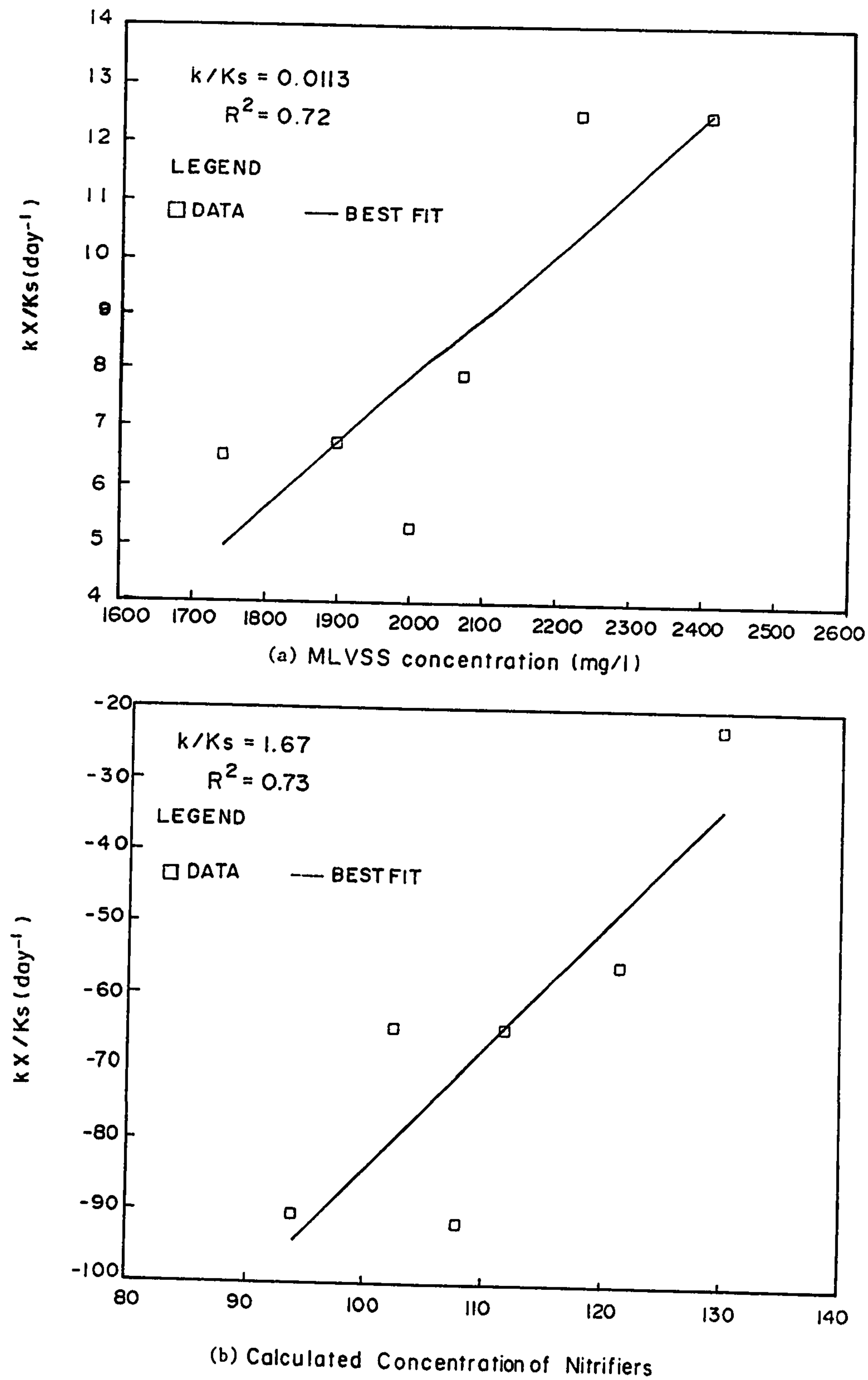


Fig. 7.5 Determination of Specific First-Order Rate Constant

reported by Rozich and Castens(35).

In order to evaluate yield coefficients for heterotrophs (Y_h) and nitrifiers (Y_n) the following relationship can be used.

$$f = \Delta X_N / (\Delta X_N + \Delta X_V) \qquad (7.7)$$

where ,

f= fraction of nitrifiers = 0.054

ΔX_N = production rate of nitrifiers (M/T)

ΔX_V = production of hetrotrophs (M/T)

$$\Delta X_N = Y_n Q (TKN_{in} - TKN_{out}) / (1+b\theta c) \qquad (7.8)$$

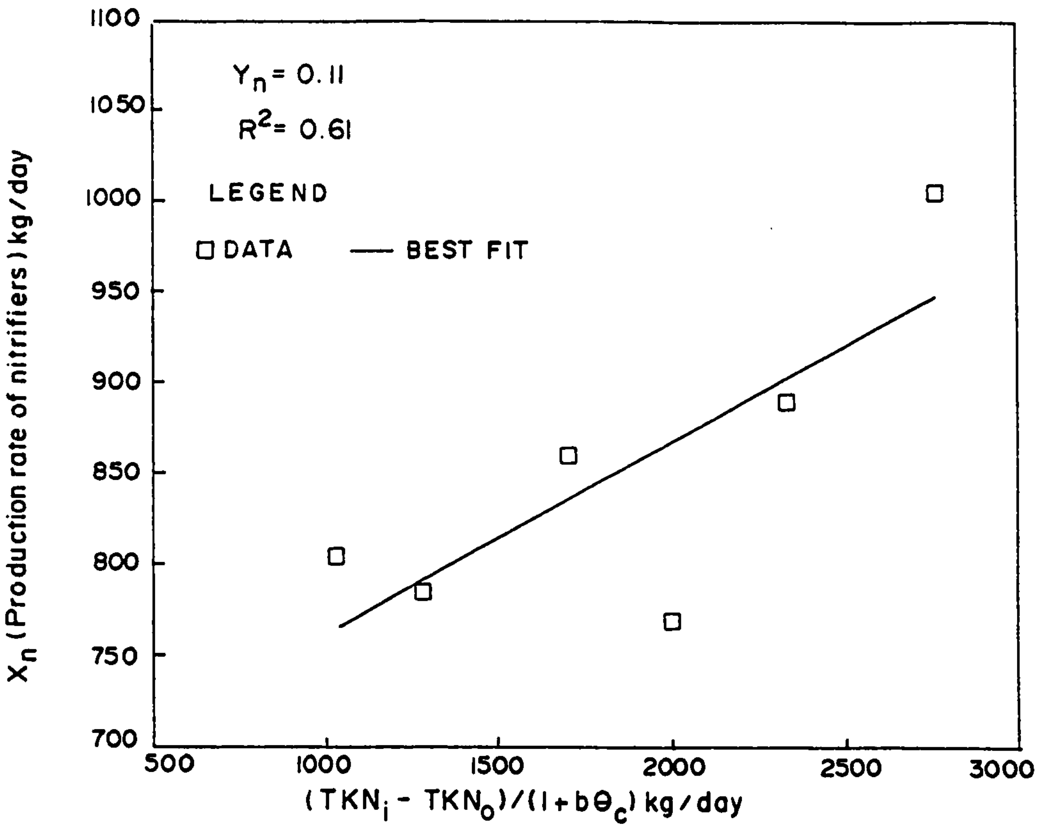
$$\Delta X_V = Y_h Q (BOD_{in} - BOD_{out}) / (1+b\theta c) \qquad (7.9)$$

where Q is the wastewater flow rate ($L^3 T^{-1}$), b is the first order decay coefficient (T^{-1}). At steady state , sludge production rate can be equalled to the sludge wastage rate ie.

$$\Delta X_N + \Delta X_V = Q_{SL} X^R \qquad (7.10)$$

where Q_{SL} and X^R respectively denote the sludge wastage rate ($L^3 T^{-1}$) and VSS concentration in return sludge ($M L^{-3}$).

The plant is operated to maintain a cell residence time of 17 days and therefore knowledge of the sludge rate mass wastage rates would allow the estimation of the production rates of heterotrophic and nitrifying bacteria. For activated sludge system, decay rate ranges between 0.03 and 0.06 (10). If we assume the decay rate for the system is 0.05 , then the yield coefficient for heterotrophs and nitrifiers (Y_h and Y_n) can be determined by plotting X_V versus Q (BOD_{in} - BOD_{out}) / ($1+b\theta_c$) and X_N versus Q (TKN_{in} - TKN_{out}) / ($1 + b\theta_c$) respectively. Figure 7.6 depicts this linear relationship with a calculated Y_h of 0.71 while Y_n was equal to 0.1 Once again the yeild coefficients agree well with the literature values (10,11,and 35).



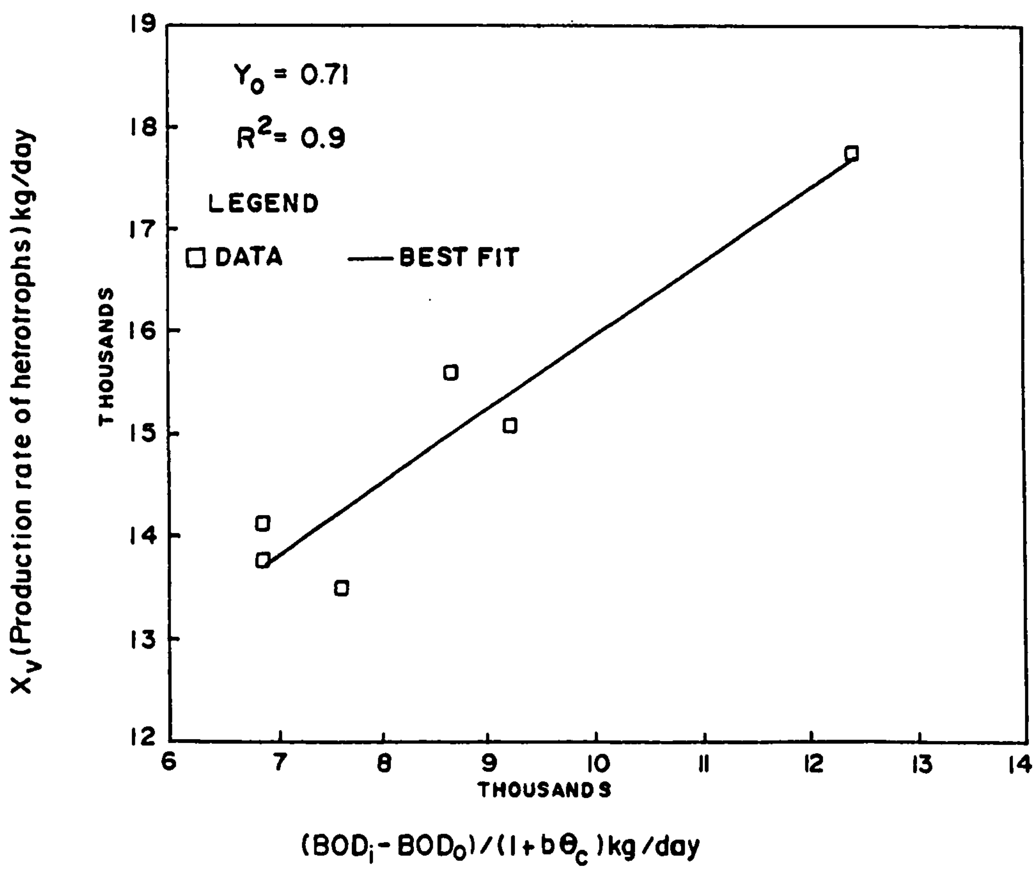


Fig. 7.6 Determination of Yield Coefficients

Chapter 8

CONCLUSION

The performance of carrousel oxidation ditch system in the 55 MGD wastewater treatment facility at Dammam, Saudi Arabia was evaluated. The carrousel system which was mostly aerobic except for the first reach, achieved effluent BOD_5 concentrations varying from 5-51 mg/l and averaging around 8.2 mg/l resulting in over than 93% BOD stabilization. Suspended solids removal of 88% were attained but the average effluent SS was 29 mg/l and sludge volume index was about 200 ml/g Total effluent nitrogen was about 4.4 mg/l comprised of 1.4 mg/l TKN and 3.0 mg/l NO_3 -N corresponding TKN and ammonia reduction efficiencies of 93 and 99%, respectively. Effluent ammonia and nitrite nitrogen averaged at 0.05 and 0.11 mg/l, respectively. Of the 88% total nitrogen removal, nitrification -denitrification which was a linear function of the influent TKN, accounted for only 45%. The carrousel system adhered to the plug flow first -order kinetic model for carbonaceous BOD removal and nitrification with specific rate (k/K_S) of 0.0113 and 0.167 L /mg VSS-d, respectively. The observed yeild coefficients for hetrotrophs and nitrifiers of 0.71 mg VSS /mg BOD_5 and 0.1 mg VSS/mg NH_4^+- N were in good agreement with literature values.

REFRENCES

1. Beccari, M., Marani, D., and ramadori, R., " A critical Analysis of Nitrification Alternatives", Water Research, 13, pp. 185-192., 1979.

2. Argaman, Y., " Single Sludge Nitrogen Removal from I ndustrial Wastewater", Water Scince and Technology, Vol.14, pp 7-20, 1982.

3. Rozich, A.F., & Castens, D.J., "Inhibition Kinetics of Nitrificationin Continuous Flow Reactors", J. WPCF, 58(3), pp. 220-226.

4. Reeves ,Thomas G. ,"Nitrogen Removal : A literature Review ", Journal WPCF, V.44, pp.1895 - 1908 , Oct. 1972.

5. Kaufman , W.J. , " Chemical Pollution of Ground Waters " , AWWA Journal , 66 , No.3 , pp. 152 - 159 (1974).

6. Weibel, S.R., Anderson , R.J. , and Woodward, R.L. , " Urban - Land Runoff as Afactor in Stream Pollution " , WPCF Journal , 43 , pp. 2033 (1971).

7. American Public Work Association , " Water Pollution Aspects of Urban Runoff " , FWPCA Report , No. wp- 20-15 , January , 1969.

8. Process Design Manual for Nitrogen Control , " U.S. EPA , Washington DC, 1975.

9. Adams , Carl E. Jr, " Removing Nitrogen from Wastewater " , Environmental Science and Technology Journal , V.7 , NO. 8 , Aug. 1973 .

10. Metcalf and Eddy , INC, " Wastewater Engineering : Treatment / Disposal / Reuse " , Magraw-Hill Book Company , Second Edition , 1979 .

11. Knowles , G., Downing , A.L. , and Barrlet , M. J. , " Determination of Kinetics Constants for Nitrifying Bacteria , in Mixed Culture , with the Aid of Electronic Computer ", J. Gen . Mictobiology , 38 , p.263 , 1965 .

12. Downing , A. L., and Hopwood, A.P., " Some Observation on The Kinetics of Nitrifying Activated Sludge Plants " , Shweiz. zeitsch fhydrol 26 , No2 , P.271 , 1964

13. Courchaine , R. J. , " Significance of Nitrificatiion in stream Analysis - Effect on Oxygen Balance " , WPCF Journal , 40, 5 , 835 , 1968 .

14. Engel, M.S., and Alexander, M., " Growth and Metabolism of Nitrosomonas Europaea", J. Bacteriology, 76, pp. 217-222, 1958.

15. Meyerhof, O., " Untersuchungen Uber Den Atmungsvorgany Nitrifizierenden Bakterien", Pflugers Archges Physiol", 166, pp. 240-280, 1917.

16. Sawyer, C.N., Wild, H.E., Jr., and Mcmahon, T.C. ," Nitrification and Denitrification Facilities, Wastewater Treatment ", EPA Technology Transfer Program, August, 1973.

17. Downing , A.L. and G. Knowles ," Population Dynamics in Biological Treatment Plants". Presented at the 3rd conference of the IAWPR, Munich, 1966.

18. Huang, C.S., and Hopson, N.E., " Temperature and pH Effect on the Biological Nitrification process", Presented at Annual Winter Meeting, New York WPCA, New York City, January 1974.

19. Nagel, C. A., and Haworth, J. G., " Operational Factors Affecting Natrification in the Activated sludge process ", Presented at the 42ND Annual Conference of the Water Pollution Control Federation, Dallas, Texas, Oct., 1969.

20. Schwer, A. D., " Letter Communication to D. S. Parker- Metropolitan Sewer Districts of Greater Cincinnati, Process Design Manual for Nitrogen Control, U.S. EPA, Washington DC, 1975.

21. Chen, C. W., "Concepts and Utilities of Ecological Model ", J. Sanitary Eng. Div., ASCE 96 (SA5) : 1085 - 1097, 1970.

22. Adams, C. E., Krenkel, P.A., and Bingham, E. C., " Invistigation into the Redection of High Nitrogen Concentration ",

23. MacCarty, P.L., and St.Amat,P.P., " Treatment of High Nitrates Waters ", J. AWWA., 61, 659, 1969.

24. Engberg, D. J., and Schroeder, " Kinetics and Stoichiometry of Bacterial Denitrification as A Function of Cell Residence Time ", Process Design Manual for Nitrogen Control, U.S. EPAWashington DC, 1975.

25. Moore, S. F., and Schroeder, E.D., " The Effect of Nitrate Feed Rate on Denitrification ", Water Research, 5, pp.445 - 452, 1971.

26. Van deer geest, Anton T., and Witvoet, William C., " Nitrification and Denitrification in Carrousel System ", Progress Water Technology, v.8, NO.4/5, pp. 653- 660, 1977.

27. Rittmann, B.E., and Langeland, W.E., " Simultaneous Denitrification with Nitrification in Single-Channel Oxidation Ditches," J. WPCF,57(4), pp 300-307, 1985

28. Applegate, C.S., Wilder, B., and Deshaw, J.R., " Total Nitrogen Removal in a Multi-Channel Oxidation System," J. WPCF, 52(3), pp. 568-577, 1980.

29. ME-SCEC, " Preliminary Design of Water Supply, Wastewater Disposal, Groundwater Control and Stormwater Facilities in The Dammam - Alkhobar Metropolitan Area, POB 1713, Khobar 31952, saudi Arabia.

30 Viak, " Operation and Maintenance Manual, " POB 3763, Riyadh 11481, Saudi Arabia.

31. "Standard Methods for The Examination of Water and Wastewater", 16th Edition.

32. Lawrence, A.W., and MacCarty, P.L., " A unified Basis for Biological Treatment Design and Operation," J. Sanit. Eng. Div, ASCE, 96(3), 1970.

33. Shammas, N, " Interactions of Temperature, pH, and Biomass on the Nitrification Process," J. WPCF, 58(1), 52-59, 1986.

34. Pointer, H.A., " A Review of Literature on Inorganic Nitrogen Metabolism in Microorganisms," Water Research , 4, pp.393- , 1970.

35 Rozich, A.F., and Castens, D.J., " Inhibition Kinetics of Nitrification in Continuous Flow Reactors, " J. WPCF, 58(3), pp. 220-226, 1986.